ASM Local & **Transboundary Haze Study**

HAZE: Help Action toward Zero Emissions

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WASTE TO RESOURCE: ENERGY OR MATERIALS

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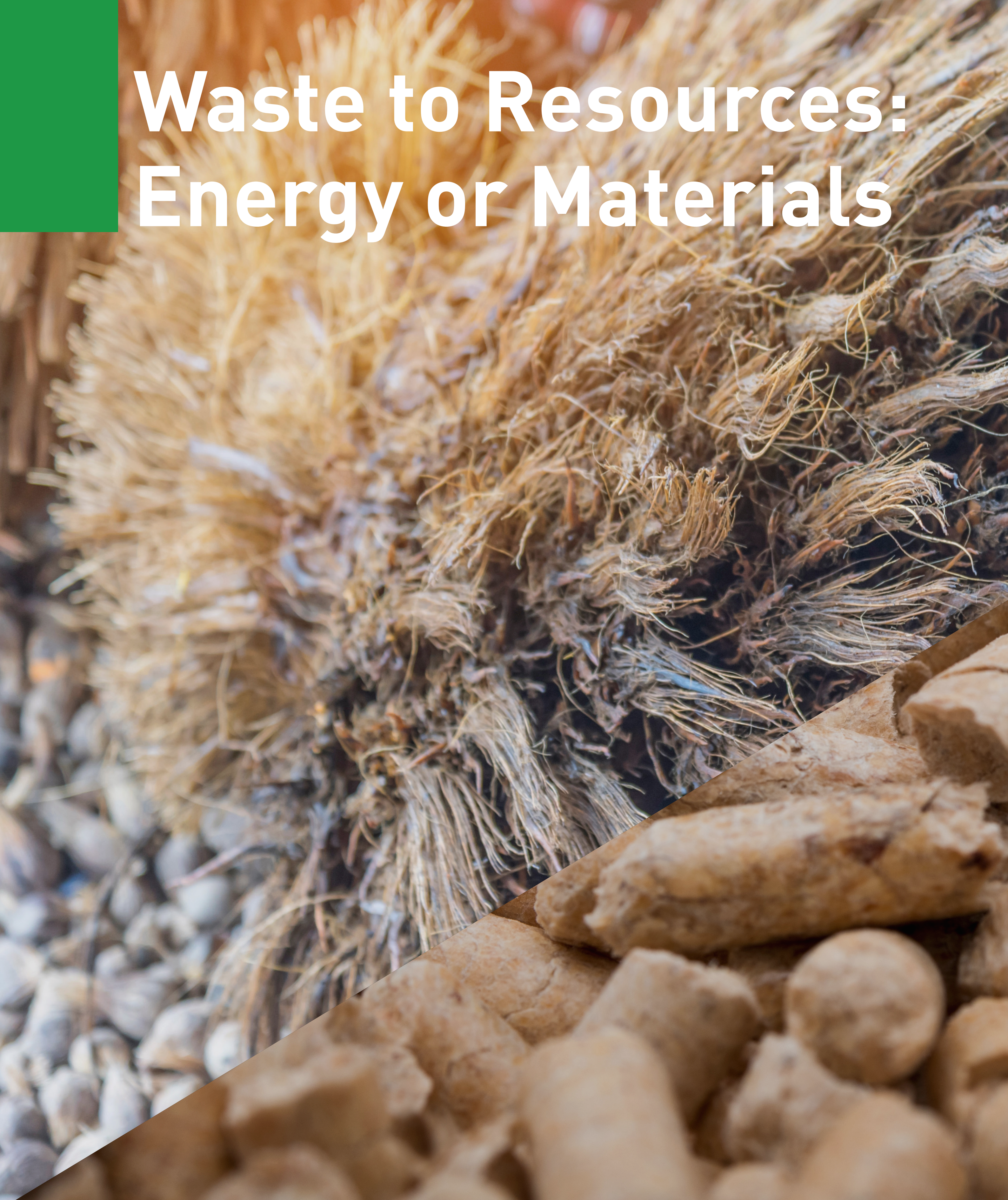
Waste to Resources: Energy or Materials



Waste to Resources: Energy or Materials

As the previous two sections have elaborated, finding long-term solutions to alleviate the regional haze problem is a complex challenge. The earlier working groups have proposed multi-pronged strategies ranging from a direct approach of causal elimination with the banning of open burning through legislation and enforcement, to a more indirect socio-political approach of dealing with the root cause which many believe to be associated to land grabbing. Other initiatives such as plans to build drainage/canal systems in peatland areas as a means of underground soil wetting have also been considered.

Working Group 3 focuses on another possible solution: an economic one. This working group focuses on the fact that a substantial amount of biomass residues are generated at various stages of the planting and harvesting process on (small-, medium-, and large-scale) plantations. A lot of residue is produced in the process of clearing undergrowth and vegetation, especially in the preparation stage. Often times, due to, among others, the time-consuming mulching process and also as a form of pest control, these plantations resort to burning the biomass residues on site, as a quick and easy way to get rid of them. As detailed in the previous working groups, such burning activity is a significant contributor to smoke in the atmosphere during the haze season. Such a situation is especially dire when the burning is done on fire-prone peatlands.

Hence, Working Group 3 explores a potential economic solution to the above scenario; the possibility of utilising the biomass produced on plantations to become a higher value bio-product. The rationale is that the creation of value for the hitherto burnt biomass should provide the incentive for plantations and farmers to view the biomass as a source of 'wealth', not 'waste'. Should this sustainable practice of economic harvesting ('earn, not 'burn'!) prove to be economically sound, there should be less plantations and farmers resorting to fire as a way to clear the biomass residues. When fires are no longer used, there should be much less incidences of haze resulting from manmade fires that have spread out of control. This would then be a positive step towards substantially reducing the severity of haze episodes in the region.

Various technologies exist to convert biomass resources into heat and power, such as gasification and direct firing combustion. However, technologies for converting bioenergy are still new and only several have been successfully commercialised. Many of these technologies are still being piloted or are in the R&D stage. This report explores technologies related to the conversion of biomass into heat and power as well as bioethanol, considering the suitability of each method as a promising strategy to help mitigate transboundary pollution experienced in the region. Case studies are also presented for possible extension into detailed studies at a later stage.

Biomass Residues

Biomass refers to any organic, decomposable matter derived from plants or animals available on a renewable basis. Its availability is distinguished between those generated on the site of growth (forests, plantations) and those generated at the point of processing. Biomass residues generated in the forests, fields or plantations are the major contributor to haze episodes in South East Asia due to on-site fires occurring during the dry, field preparation season. Additionally, parts of Malaysia and Indonesia are made up of large areas of peat forest which is also highly combustible during dry season. As explained in the previous working group report, peat forest fire becomes very difficult to control, due to its abundance of underground biomass.

For example, the island of Sumatera, Indonesia, consists of 9,680,020ha of dipterocarp forest, 7,447,358ha of peat forest, and 12,209,475ha of oil palm plantations, as shown in the map and table below. In the year 2015, it was estimated that approximately 5,385,815,232Mg of biomass could be obtained from Sumatera, with 1,675,655,508Mg of biomass from peat forests and 1,080,538,533Mg of biomass from oil palm plantations.

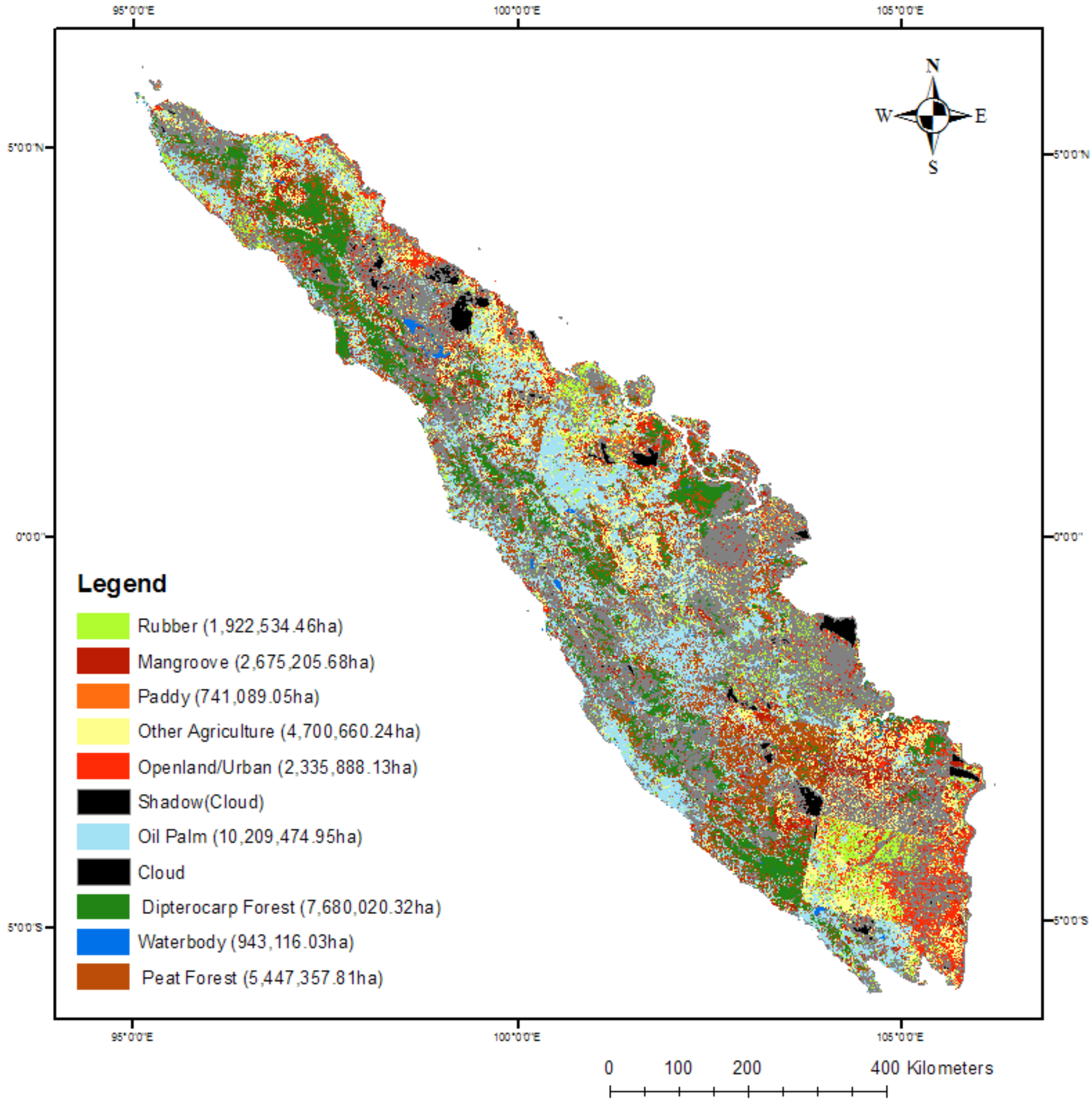


Figure 8 Land use distribution in Sumatera, Indonesia

Table 8 Land use in Sumatera in year 2015/2016

Type of Land use	Area (Ha)	Biomass (Mg/ha)	Biomass (Mg)
Dipterocarp Forest	9,680,020	149	1,439,419,021
Peat Forest	7,447,358	225	1,675,655,508
Mangrove Forest	4,675,206	250	1,168,801,419
Oil Palm	12,209,475	89	1,080,538,533
Rubber	2,922,534	2	6,517,252
Paddy	741,089	2	1,482,178
Other Agriculture	6,700,660	2	13,401,320
Non-vegetated	3,000,000	-	-
TOTAL	47,376,343		5,385,815,232

For the purpose of this report, only lignocellulosic biomass residues originating from primary or secondary forest, agricultural plantations and peat forests shall be considered. The typical composition of lignocellulosic biomass is 5-30% lignin, 19-27% hemicellulose and 30-50% cellulose (Liu et al., 2014).

Open burning of forest biomass residues and oil palm plantation biomass residues have been found to be the most likely sources of smoke haze. The chemical composition of forest biomass and oil palm plantation biomass are shown in the table below. The ultimate analysis measured the elemental contents for carbon, hydrogen, oxygen, nitrogen and sulphur (C, H, O, N, and S) which are important indicators for energy processes and gas emissions during combustion of the resource materials.

The forest biomass showed a higher value of C (48.10%) as compared to the trunk (40.64%) and frond (44.50%) of oil palm. In terms of the lignocellulosic content, which is the important composition indicator for conversion to biofuels and biochemical, Empty Fruit Bunches (EFB) have highest amount of cellulose (57.80%), while each type of biomass have similar lignin and hemicellulose contents. The higher heating value (HHV) of the biomass was also compared, where EFB has the highest value of HHV with 20.54MJ/kg, while both the trunk and frond has slightly lower HHV than the EFB, with 17.27MJ/kg and 17.28MJ/kg respectively.

Table 9 Properties of biomass

	Forest biomass a	Oil Palm Plantation Biomass		Empty Fruit Bunch (EFB) c,f
		Oil Palm Trunk b,c	Oil Palm Frond d,e	
Proximate analysis (wt% dry basis)				
Moisture content	-	8.34	16.00	4.68
Volatile matter	-	79.82	83.50	76.85
Fixed carbon	-	13.31	15.20	5.19
Ash	1.70	6.87	1.30	18.07
Ultimate analysis (wt% dry basis)				
Carbon (C)	48.10	40.64	44.58	46.36
Hydrogen (H)	5.99	5.09	4.53	6.44
Oxygen (O)	45.72	53.12	48.80	38.91
Nitrogen (N)	-	2.15	0.71	2.18
Sulphur (S)	-	-	0.07	0.92
Lignocellulosic content (wt% dry basis)				
Cellulose	45.80	45.90	50.33	57.80
Hemicellulose	24.40	25.30	23.18	21.20
Lignin	28.00	18.10	21.7	22.80
HHV (MJ/kg)	-	17.27	17.28	20.54

(Source: a. Saidur et al., 2011 b. Nimit et al., 2012 c. Oil palm biomass (www.bfdic.com)
d. Guangul et al., 2012 e. Abnisa et. al., 2011 f. Abdullah and Sulaiman, 2013)

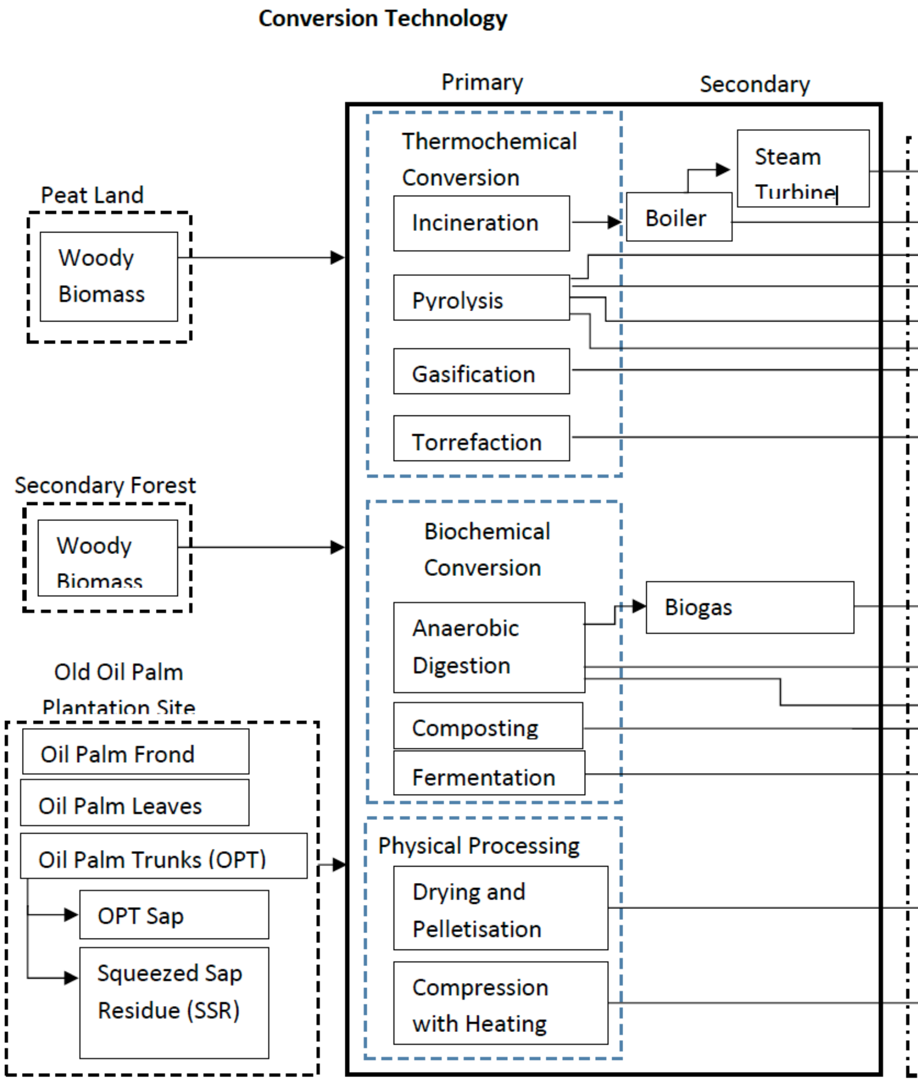
Conversion Pathways

Transforming biomass residues to value-products and energy or biofuels involve thermochemical, biochemical, and physical conversion processes. The pathway is best illustrated in Figure 9. Products that can be derived from biomass can be categorised based on economic value, namely low, medium and high value products, as shown in the table below. Low value products, such as compost, require very low investment cost and simple conversion technologies. Heat and power products from biomass are considered as medium value products, while biofuel and biochemicals products require high investment cost resulting in the highest product value among the three categories.

Table 10 Types of product derived from biomass

Type of product	Product
Low value product	Compost
Medium value product	Heat and power
High value product	Biofuel and bio-chemicals

Composting (low)-Aerobic composting is the most commonly used biological treatment for the conversion of organic portions of waste. It is defined as the biological decomposition and stabilisation of organic substrates under conditions that allows development of thermophilic temperatures as a result of biologically produced heat and compost.



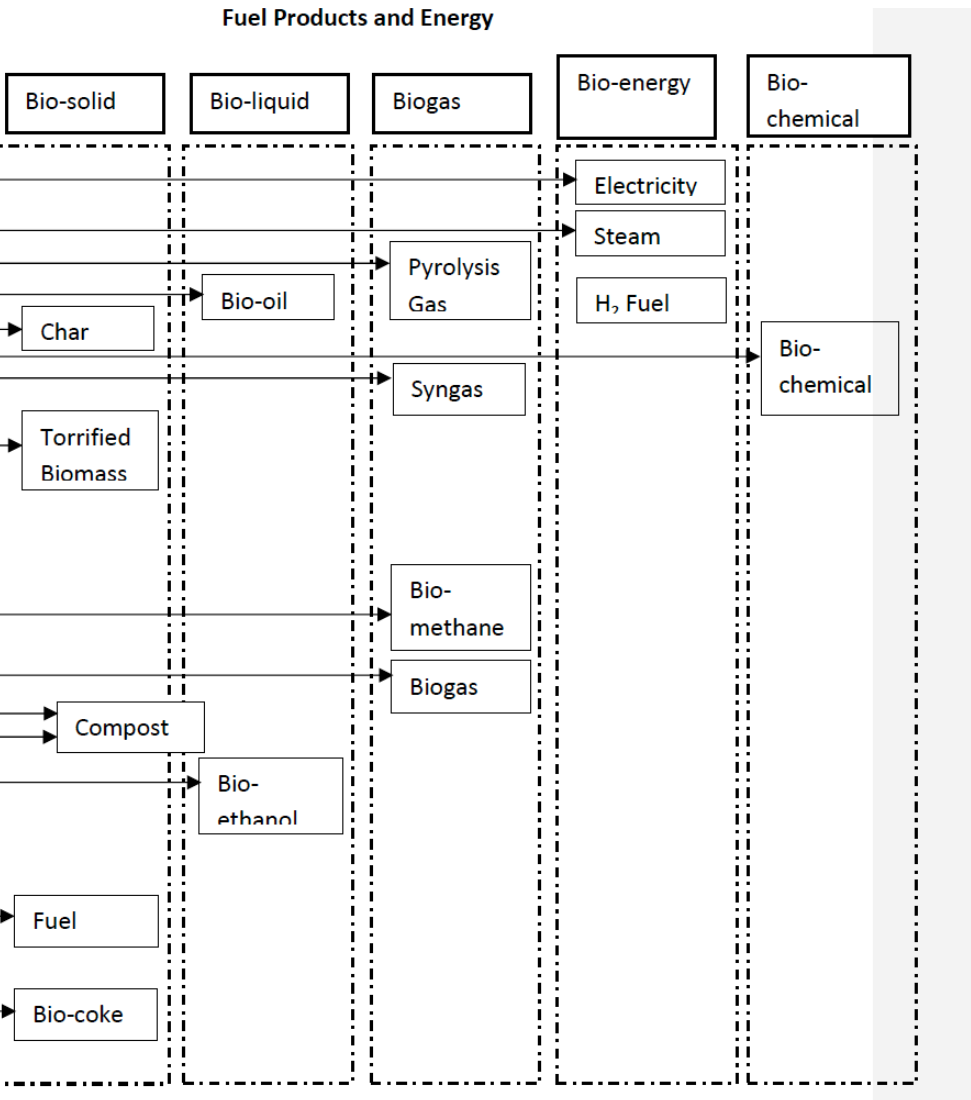


Figure 9 Conversion of biomass to product

Biofertilizer microorganisms are incorporated into the biomass compost to produce bioorganic fertilizer or biofertilizer. Examples of biofertilizer microorganisms are N_2 fixing bacteria (*Rhizobium* spp., *Azospirillum* spp. *Azotobacter* spp.), phosphate solubilising microbes (*Bacillus* spp., *Klebsiella* spp., *Penicillium* spp) and plant-growth-promoting rhizobacteria, (*Azotobacter* spp., *Enterobacter* spp.).

Several large plantation companies in Malaysia, e.g. Federal Land Development Authority (FELDA), Federal Land Consolidation and Rehabilitation Authority (FELCRA) and Sime Darby are embarking on their own biofertilizer production, especially for oil palm. Oil palm production has largely been dependent on chemical fertilizers. These companies' interest in biofertilizer is partly due to the increasing cost of chemical fertilizers, particularly urea, and partly to awareness on green technology for crop production. It is estimated that 60% of costs of production in oil palm are on fertilizers. On top of that, Malaysia is facing infertile soil due to the loss of top soil and years of planting on the same soil, in addition to increasing pest and diseases.

Power generation (medium)-Conversion of biomass resources to power and heat requires several steps including biomass fuel preparation (pre-treatment, pre-drying, size reduction) and selection of conversion technology. The fuel preparation (pelletising) process as shown in the figure below improves the physical, chemical and combustion properties over those of the raw biomass. It also improves the characteristics of the biomass in its utilisation as direct fuel as shown in the table below.

Biomass → Drying → Grinding → Pelletising

Figure 10 Process of biomass pelletising

Table 11 Characteristics of shredded and pelletised Empty Fruit Bunch (EFB)

Characteristics	Shredded EFB	Pelletised EFB
Calorific value, CV (kJ/kg)	8500	15051
Moisture content (%)	45	12
Amount of fuel required to produce 1 tonne of steam	350-400 kg	200 kg
Fuel cost (RM/tonne)	RM 15 – 70	RM 450
[1]Bulk Density (kg/m^3)	150	689
[1]Combined Cycle Efficiency (%)	31.8	32.3
[1]Electricity generation	0.063	0.072
Cost (USD/kWh)		
Transportation cost	RM 45/tonne for distance of 80-100 km, extra cost will be charged for additional distance	

([1]Source: Pirraglia *et al.*, 2012)

Biomass to power conversion systems fall into two categories, i.e. the direct-fired and gasification systems. The direct-fired category includes stoker boilers, fluidised bed boilers, and co-firing. The gasification category on the other hand includes fixed bed gasifiers and fluidised bed gasifiers. The technologies for conversion of biomass for power generation are summarised in the table below.

Table 12 Summary of Biomass to Power Conversion Technologies

Biomass Conversion Technology		Common Fuel Types	Feed Size (inches)	Moisture Content (%)	Capacity Range (MW)
Direct Firing	Stoker grate, underfire stoker boilers	Sawdust, bark, chips, hog fuel, shavings, end cuts, sander dust	0.25 - 2	10-50	4-300
	Fluidised bed boiler	Wood residue, peat, wide variety of fuels	< 2	< 60	300
	Cofiring—pulverised coal boilers	Sawdust, bark, shavings, sander dust	< 0.25	< 25	1000
	Cofiring—stoker, fluidised bed boilers	Sawdust, bark, shavings, hog fuel	< 2	10-50	300
Gasifiers	Fixed bed gasifier	Chipped wood or hog fuel, shells, sewage sludge	0.25 - 4	< 20	50
	Fluidised bed gasifier	Most wood and agriculture	0.25-2	15-30	25

The current application of biomass to power in Malaysia is focused on the utilisation of EFB due to its high HHV content and abundant feedstock from palm oil mills. To date, there is no implementation of forest biomass or oil palm plantation biomass to power in Malaysia. Nevertheless, forest biomass and oil palm plantation biomass has been shown to have similar HHV content as EFB (20 MJ/kg and 17MJ/kg respectively), hence making these materials a potential source for power generation.

Malaysia started utilising biomass in power generation in the year 2003, where a 7.5MW integrated biomass co-generation plant was established in FELDA Sahabat, Lahad Datu, Sabah by the FELDA Global Ventures Holdings Bhd (FGV). The power plant uses EFB as feedstock generating heat and power for demands within the company mill (kernel crushing), refinery and surrounding communities. The project was the first Clean Development Mechanism (CDM) Project in Malaysia. With the investment cost of RM38 million, the biomass power plant successfully reduced 377,902t of CO_2 emission by the end of 2012 (CDM, 2006). The project is marked as one of the key success of renewable energy development in Malaysia as it is the first large scale co-generation plant in the world to solely utilise treated EFB combustion fuel. Malaysia's industries were encouraged by the government to invest R&D efforts and to study the feasibility of applying this model throughout the country's industrial sector.

Biomass to Biofuel/Biochemical (high)-Maximum valorisation (value) of biomass can be achieved by its conversion into biofuels and biochemicals. The conversion of lignocellulosic biomass to biofuels and biochemicals follow similar routes that consists of pretreatment, hydrolysis, microbial conversion and purification, as illustrated below. While the process of conversion to biofuels in the form of bioethanol has been commercially established, the processes for conversion to other biofuels such as butanol and biochemicals are not commercially available at the present time.

Pretreatment → Hydrolysis → Coversion → Purification

Figure 11 Process of conversion into biofuels and biochemicals

Pretreatment is required to disrupt the lignin outer layer and expose the carbohydrates for hydrolysis to produce monomeric sugars compatible for fermentation. This may encompass physical (i.e. crushing, pulverisation, etc.) and thermo-chemical processes optionally coupled with biological pretreatment.

Hydrolysis refers to processes that convert the polysaccharides into monomeric sugars prior to microbial conversion. There are two different types of hydrolysis; acid hydrolysis and enzymatic hydrolysis. While acid hydrolysis is able to produce high yields of simple sugars, it suffers from the disadvantage of extensive acid requirement, costly acid recycling and undesirable degradation of products which renders it commercially less appealing. Enzymatic hydrolysis needs an efficient pretreatment which increases the porosity of the lignocellulosic substrate, making the cellulose more accessible to cellulases and improving the enzymatic digestibility of the substrate. Cellulase enzymes from the fungus *Trichoderma reesei* have a proven efficiency and productivity in this function. Advances in enzyme-based technology for ethanol production have been substantial over the years, and as a result, ethanol production costs have been reduced considerably.

The monosaccharides formed by the hydrolysis process are then fermented to produce ethanol (conversion). Industrial yeasts such as *S. cerevisiae* have proven track records with high yields in the brewery and wine industries. However, wild *S. cerevisiae* is capable of fermenting onl C6 hexoses which makes it incompatible for saccharification of a large proportion of hemicellulosic biomass mainly constituted by pentose sugars such as D-xylose (Martin et al., 2002). In response to such limitations, genetically engineered microorganisms have been extensively employed and are capable of concurrently fermenting pentose and hexose sugars with little amounts of toxic end-products, while having high tolerance to chemical inhibitors derived from the pretreatment and hydrolysis processes. Process variations such as a simultaneous saccharification and fermentation (SSF) process has been developed to enable parallel hydrolysis and fermentation reactions in one single reactor, but these processes tend to compromise on yields due to different operating temperatures of the hydrolysis and fermentation processes.

In the final step, the ethanol is then recovered and purified through a distillation process incorporating normal and azeotropic distillation.

Economic Potential

Economic conversions of biomass range from low investment and low returns biofertilizer to high investment and high returns biochemicals. Biofertilizers are economical only when the biomass residues are readily available for conversion without additional transportation costs such as EFB from palm oil mills. Biopellets can command a higher price, but only if exported to energy deficient countries. It is not economical for local consumption due to the abundance of biomass available locally and the extra costs involved in the pelletising process. Biochemicals on the other hand are not fully commercialised yet. Most of the biochemicals produced are still in piloting stage, hence the lack of data available for the purpose of this study. Thus, this report focuses on the economic potential of biomass-to-power and biomass-to-ethanol conversions.

Taking off from the FELDA case stated earlier, this report presents the economic potential using 2,000t/d forest and oil palm plantation biomass (OPF and OPT) as the feedstock for power generation with main focus on electricity production. The proposed technology is a 27MW capacity direct combustion system with a 76% efficiency comprising of a pre-treatment drying system, fluidised bed boilers for conversion of biomass to heat and steam, and generation of electricity through extraction-condensing turbine. The biomass feed stock used for power generation is assumed to have calorific value of 15.82MJ/kg with 16% moisture content (dry basis) (Fiseha et al., 2012). The direct combustion technology has a 30-year plant life with investment cost of USD900/kW and USD1050/kW for boiler and turbine respectively.

Using the net present value (NPV) economic analysis, the correlation between the minimum electricity production cost and the equity financing is presented in Figure 12. Minimum electricity product cost ranged from USD0.23/kWh to USD0.19/kWh with variations of equity financing share of 30% to 70%. The minimum product cost is consider high even with the equity financing adoption as compared to the current feed-it-tariff (FiT) incentive of USD0.10/kWh.

The case study is repeated with different capacities (2000t/d, 1000t/d, and 500t/d)as shown in Figure 12. It can be seen that there is only a marginal reduction in the minimum electricity price (ranged from USD0.24/kWh to USD0.19/kWh) due to economy-of scale capacity increment. This is due to the high fixed investment cost (approximately USD3000/kW), while the current FiT scheme is relatively low. The low FiT scheme renders the biomass-to-power to be less competitive at the current power industry market.

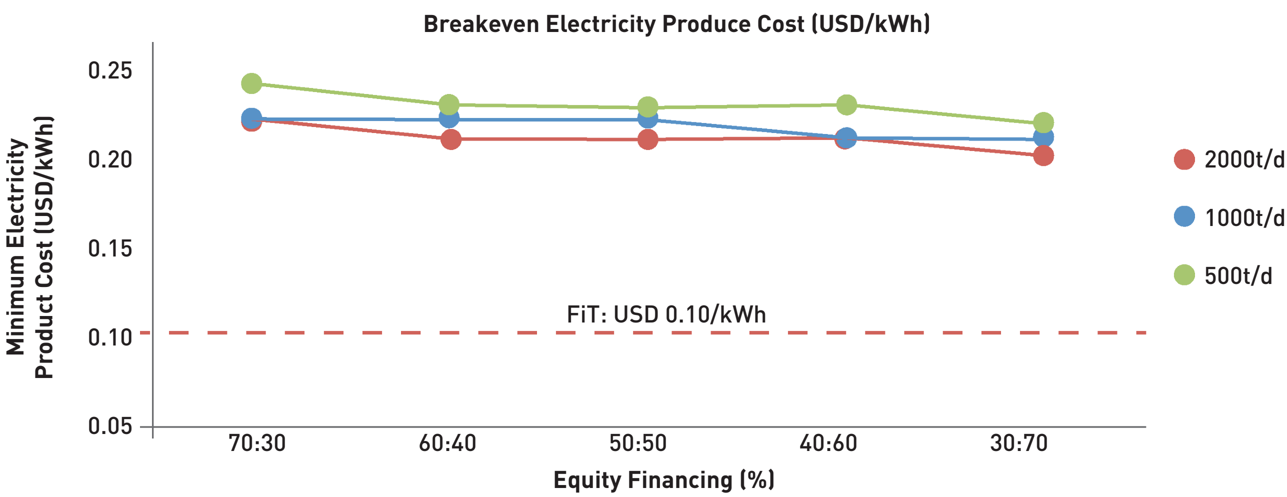


Figure 12 Breakeven of electricity selling price for biomass-to-power in Malaysian context

Electricity price for changes of equity financing for conversion of biomass to power-For the case of biomass to bioethanol, an economic evaluation was also performed to determine the minimum selling price of ethanol and power in the current economic conditions.

The case study for biomass to bioethanol presents the economic potential using 2000t/d biomass as the feedstock. The proposed technology is enzymatic hydrolysis followed by fermentation with the cellulosics content in biomass of 70% and conversion yield of the cellulosics to C5 and C6 sugar of 95%. The fermentation process uses high substrate tolerant recombinant yeast capable of converting 30% fermentable C5and C6 sugars to 15% ethanol. The technology has a 30-year plant life with a total capacity cost of USD1,094,065,600.00 The major variable cost is assumed to be the enzyme cost of about USD0.6/gal of ethanol.

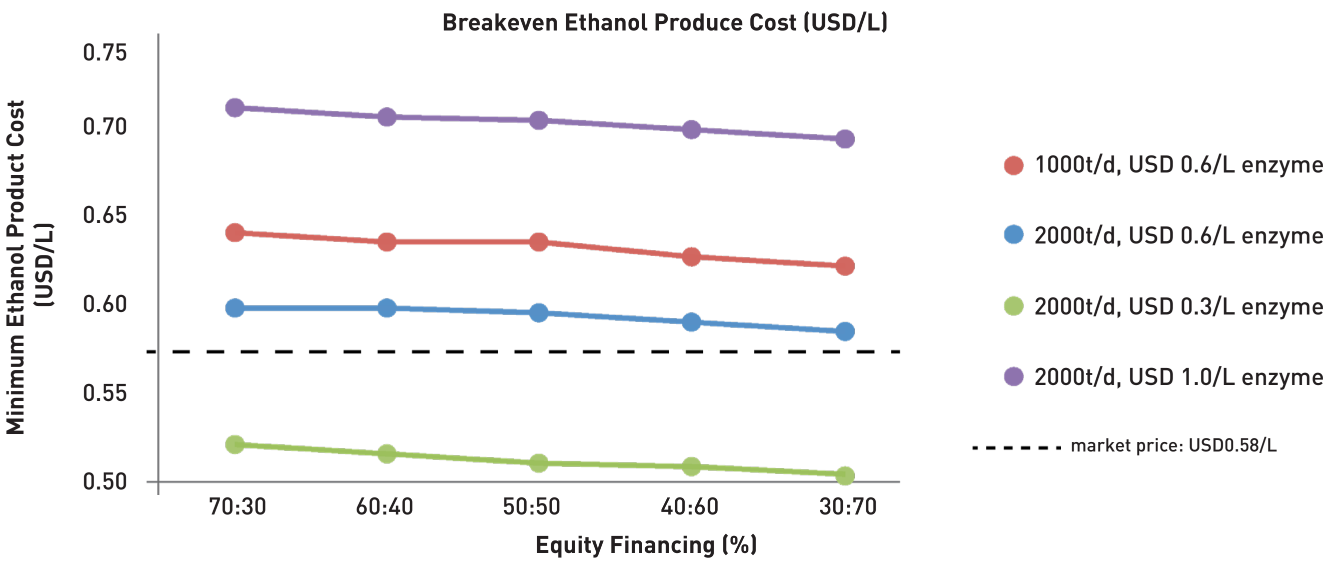


Figure 13 Breakeven of ethanol selling price for biomass-to-ethanol in Malaysian context

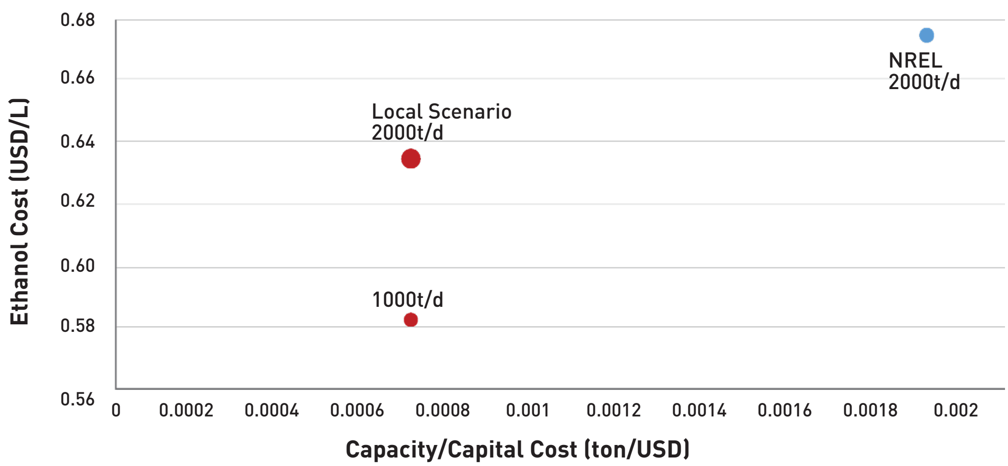


Figure 14 The price of ethanol with different capacity and capacity cost

Using the NPV economic analysis, the correlation between the ethanol production cost and equity financing is presented in Figure 13. For a production capacity of 2000t/d, the production cost ranged from USD0.64/L to USD0.62/L with the movement of equity financing share from 30% to 70%, which is higher than the current market ethanol price of USD0.58/l. Figure 13 also shows the variation of ethanol production cost at different capacities and with variation in enzyme costs. The plot demonstrates that economic viability from lower ethanol production cost can be achieved at favourable equity financing ratios, higher capacities (due to economy of scale) and lower enzyme costs.

Figure 14 shows the price of ethanol for different capacities and capacity costs. The analysis compared the local scenario as presented above to the U.S scenario as per the National Renewable Energy Lab (NREL) report. In U.S scenario, the production cost is USD0.67/L while in the local scenarios it is USD0.58/L and USD0.63/L for capacities of 1000t/d and 2000t/d, respectively. It is shown that with the localised condition, the value of ethanol cost can be significantly reduced.

Table 13 Ethanol production cost (USD/L) reduction by improving the debt: equity ratio or interest rate

Debt : Equity ratio	Interest Rate		
	8%	5%	3%
95:5	0.77	0.61	0.52
70:30	0.73	0.60	0.53
60:40	0.71 (0.57[a])	0.60	0.53
50:50	0.69	0.60	0.54
40:60	0.67	0.59(0.52[b])	0.54

Table 13 presents the potential of ethanol production cost reduction by improving the debt: equity (D:E) Ratio or interest rate (iR). It is shown that at the iR of 3%, the ethanol production cost could be reduced significantly and makes it competitive to current market value.

The two case studies presented above reviewed the economic potential of localised biomass-to-power and ethanol in current market. For biomass-to-power, the current FiT scheme is relatively lower than the electricity production cost, rendering the biomass-to-power option less attractive to investors. The rate of FiT scheme in Malaysia was established in year 2011, and is considered not up-to-date on current renewable resources market as various renewable energy resources have been more economically competitive in recent years. In order to promote the utilisation of biomass to power, the current Fit should be reviewed and revised.

The case study of biomass to ethanol, on the other hand, demonstrated a favourable scenario to investors demonstrating that with a financial interest rate of 3%, ethanol production is economically competitive in the current market. Nevertheless, the current interest rate stands at the rate of 5%-8% and with high cost of enzyme in Malaysia, there needs to be some policy and technology intervention to enable a sustainable bioethanol industry in Malaysia.

Challenges of Biomass Conversion in Malaysia

In addition to pricing constraints as discussed above, there are also other challenges in the way of biomass conversion in Malaysia, including investment, technology or technical, transportation and logistics, and also socio-cultural awareness on the issue. The following discussion details each of these challenges in turn.

Briefly, full-scale investment into biomass conversion technologies in Malaysia is hindered by several factors, including limited access to biomass feedstock, limited financing resources for biomass conversion technologies, and a lack of support from domestic market.

The technological and technical challenges of biomass conversion into Malaysia can be divided according to type of product. Composting (low value) technology is mature and anaerobic composting process is commonly applied. However, this technology would result in large carbon footprint, and would lead to odour problems if there is no proper containment of biomass waste being composted.

For biomass-based power generation (medium value), gasification and pyrolysis are generally less mature than direct combustion, and are more vulnerable to technical breakdowns, accidents, or explosions due to malfunctioning. In particular, pyrolysis has low thermal stability, and has been associated with corrosion problems, which may hinder further upgrading of the product into bio-oils (for more market value) (McKendry, 2002a).

In terms of biochemical and biofuel production (high value), biorefinery processes designed to synthesise biochemicals (i.e. lactic acid, bio-sugar, polylactic acid, food additives, zeolite and catalysts, etc.) is still at its infancy in Malaysia. This is manifested in the lack of pilot or demonstration plants, a deficit of market-focused research and development (R&D), and a lack of local market support for these technologies due to their high technical and financial risks. IPs for conversion technologies for biochemical production are now highly prized and are in the domain of large international private companies such as DuPont and DSM.

Moving on, costs associated with transportation and logistics vary for different biomass residues and the sites of its availability. Biomass which is generated post-processing such as EFBs, rice husks and wood chips are available at the processing sites so transport costs are minimised. However, for non-processed biomass such as oil palm tree trunks, rice straws, and non-processed forest products, the transportation costs are a function of its distance to the transportation network. Cost estimates range from RM0.20 to RM10 per kilometre per tonne based on road transport (trucks), but may differ upon the availability of other modes of transport such as trains or barges. However, in these cases, transport interfaces need to be factored in. For long distance haulage, compression and pelletisation of biomass resource into compact forms (i.e. pellets or briquettes) would be required (BioEnergy Consult, 2016).

Low socio-cultural awareness among stakeholders on the importance and benefit of achieving sustainability via maximum harnessing (reuse) of biomass could be another challenge in Malaysia. Locally, the concept of carbon footprinting is not widely adopted or understood, and sustainability is not a major concern in business decision-making. Moreover, in Malaysia, the concept of environmental sustainability is not ingrained among the population. Among the three pillars of sustainability (i.e. economic, social and environmental), practical engineering considerations only emphasise the first two aspects. Without the enforcement of regulations, application of biomass resources for the sake of environmental protection is not imperative for existing businesses.

The full Working Group report in the Annexe provides a biomass to pellet business model that can potentially overcome logistical issues of biomass handling, storage, and transportation. The full report also provides a case study in Thailand where socio-cultural awareness was boosted through local initiatives.

Science and Policy Interface

The Malaysian Government has declared biomass as a potentially important source of energy for Malaysia. In order to promote and enhance the development of biomass energy, several energy policies have been developed, including:

a) Fifth Fuel Policy (2000)
b) National Bio-fuel Policy (2006)
c) National Green Technology Policy (2009)
d) National Renewable Energy Policy (2010)

These policies have been developed based on three principals, which focus on supply, utilisation and the environment. The Government of Malaysia has also launched several programmes to explore and promote the use of renewable energy as an alternative fuel source. The on-going incentives and programmes include FiT, EU-Malaysia Biomass Sustainable Production Initiative (Biomass-SP), East Coast Economic Region (ECER), Palm Oil Industrial Cluster (POIC), and the National Biomass Strategy (NBS) 2020. The applicability, or lack thereof, of these existing policies into the proposed strategies will be discussed further in the 'way forward' section further below.

Conclusion

As haze episodes may evolve into potentially complex emergencies, the development of an effective technology for biomass utilisation is critical. Hitherto, burning has been the preferred method for clearing biomass residue as it is the most economical form of land clearance. Hence, it can be said that one of the main causal factors of the transboundary haze is in fact economic motivation. In the same way, this working group proposes an alternative economic motivation, to dis-incentivise burning and incentivise 'earning' instead. The group argues that if an economically sound method can be presented to plantations and farmers, this will be a great motivator for them to move away from fire-based methods of land clearing, which do not yield any economic benefits.

The above discussion has detailed how biomass residue can potentially be turned into value-added products such as compost, fuel, power, and bio-chemicals. This will potentially create economic benefits for the stakeholders involved, and ultimately reduce open burning practices and contribute to haze mitigation. However, the preliminary findings of this working group show that at current local economic conditions, products from biomass would be more expensive than the currently available energy and fuel. In addition to this economic challenge, other issues like investment, transportation, and awareness may create further resistance to this solution.

However, such a situation is not all that stark. There have been many instances where a potentially beneficial strategy is not immediately economically viable and cannot break even, due to, among other, the lack of market demand. It is then the role of the government or other interested parties to create various incentives to close the economic gap, to enable these strategies to take hold in the market, until demand is sufficient. Potential approaches in the effort to make biomass residue conversion in Malaysia viable are expanded in the 'Way Forward section' below.

Way Forward

As mentioned above, governments and other interested stakeholders should play an important role in creating various incentives to create markets for certain beneficial technologies and to make them more economically feasible. Especially in the case of the transboundary haze, which amounts to billions of ringgit of economic losses throughout the Malaysian economy on an almost yearly basis, the Government of Malaysia should be even more interested to invest in a solution that could have a positive trade-off towards a haze free Malaysia.

While the utilisation of biomass for lower value products such as fertilizers and fuel in direct combustion is now well established in the Malaysian commercial domain, there are still challenges in moving up the value chain to biochemical conversion (which include the biofuels ethanol or butanol). Through the years, the Government of Malaysia has formulated policies and programmes related to the utilisation of biomass for economic gains (as detailed above). However, these policies lack specificity and still have room for improvement. In particular, to complement existing policies, further policies should be developed for

(1) securing biomass resources;
(2) supporting biotechnologies; and
(3) creating a platform for biomass product marketing

One hurdle related to this is the Malaysian Government's lack of mandate on biodiesel B5 and bioethanol E10 which hinders full uptake on any bioethanol investment. Without a firm biofuel policy mandate, the case for bioethanol is hard to defend due to its high investment cost. This is further compounded when investments are undertaken through the acquisition of bank loans, hence increasing operational costs due to interest repayments. Working Group 3 proposes that the government provides significant funding involvement (that can be converted into equity) to minimise the interest charges from massive loans. In other words, from a purely financial standpoint, the equity-loan ratio needs to be optimised to maximise margins on the sale of ethanol. This will help enable ethanol to competing against traditional fuels at a similar price point.

The economic case for bioethanol or any biochemical is not helped by the imperfect development of the local biomass market. As it stands, the local biomass market is quite fragmented and unorganised, and is far from a full-fledged commodity market. In order to ensure proper management and trading of biomass, this working group proposes the establishment of a 'Centre for Sustainable Mobilisation of Biomass Resources', which would include within its remit biomass logistics and trade centres. The Centre and complementary regional branches should help to optimise logistics and trading organisation, where different biomass fuels such as firewood, chips, pellets and energy crops can be marketed at guaranteed quality and prices. Both of the above suggestions will also go a long way in helping to create the market demand among public which is so needed for a sustainable commodity.

Admittedly also, current research and development on potential biomass utilisation directly related to the mitigation of the haze problem is still at its infancy. There is a need for more research funding in the area, as well as the development of databases and support systems for researchers. More specifically related to this report, the choice of technology or combination of technologies to be selected for possible demonstration or even commercialisation requires a more detailed study. This is to determine with greater accuracy on the investments needed and the possible economic returns to complement the social and environmental benefits of potential solutions to the haze problem.

Annex C:

Waste to Resources: Energy or Materials

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1 Introduction

Regional haze episodes have now evolved into an annual affair, with the only uncertainty being its severity in any particular year. While the direct cause is crystal clear, its remedy is much less simpler. Finding long term solutions to alleviate the problem has turned out to be rather complex with multi-pronged strategies, ranging from a direct approach of causal elimination through the banning of open burning through legislation and enforcement to a more indirect socio-political approach of dealing with the root cause, which many believe to be associated to land grabbing. Other initiatives such as plans to build drainage/canal systems in peat land as a means of underground soil wetting have also been considered.

One possible solution which shall be discussed in this report is the utilisation of the biomass for higher value bio-product. The rationale is that the creation of value for the hitherto burnt biomass shall provide the impetus to consider the biomass as a source of wealth to be translated into a sustainable practice of economic harvesting. Various technologies exist to convert biomass resources into heat and power such as gasification and direct firing combustion. On the other hand, technologies for converting bioenergy is still new and only several are commercial today while others are being piloted or in R&D stage. This report discusses the technologies of converting biomass into heat and power as well as bioethanol as one of the promising strategies to mitigate the transboundary haze pollution encountered by the ASEAN countries in recent years. Case studies are also presented for possible extension into detailed studies later.

2 Biomass

2.1 Biomass definition & categorisation

Biomass refers to any organic, decomposable matter derived from plants or animals available on a renewable basis. There are two different types of biomass residues:

a) Biomass generated on the forest, fields or plantations, such as forest residues, oil palm tree trunks and fronds and rice straws,

b) Biomass generated at the point of processing, such as oil palm empty fruit bunches and kernel shells, and rice husks.

The first type of biomass residues generated in the forests, fields, or plantations are the major contributor to forest fire which caused haze in Southeast ASEAN. These residues are abundant, and in dry seasons they become very dry with high potential of catching fires from very small flames or even burning ambers like cigarette butts that could lead to raging fires and massive haze. On the other hand, Sumatra and Kalimantan possess large areas of peat forest, which is highly combustible during dry season. Therefore, the problem is further compounded in peat forests where a lot of biomass exists underground and once fire starts, it becomes very difficult to control. In this study, we focuses on the utilisation of biomass generation in forest and plantation, which are i) secondary forest biomass, ii) oil palm plantation biomass, and iii) peatland biomass.

2.1.1 Secondary forest biomass

A secondary forest is a forest or woodland area which has regenerates largely through natural processes after significant human and/or natural disturbance of the original forest vegetation over an extended period (Chokkalingam and Jong, 2001). Biomass in secondary forest can be categorised into three main types: the above-ground biomass, below-ground biomass, and dead wood (Food and Agriculture Organization of the United Nations, 2010), as explained in Table C-1. Biomass generation of secondary forests varies in relation to factors such as site conditions (soil and altitude), time of settlement and the crop-fallow cycles, the type and intensity of land use during the cropping stage, and the prevalence of disturbances such as accidental burning during the fallow stage (Dominic, 2002). Above-ground biomass has higher economic value as it contains higher amounts of cellulose, hemicellulose, lignin and a small amount of other extractives, which could be converted into energy-related resource.

Table C-1 Type of biomass in secondary forest with definition and example (Food and Agriculture Organization of the United Nations, 2010)

Type of biomass in secondary forest	Definition	Example
Above-ground biomass	All living biomass above the soil	Stem, stump, branches, bark, seeds, foliage
Below-ground biomass	Fine roots of less than 2mm diameter are excluded because these often cannot be distinguished empirically from soil organic matter or litter	roots
Dead wood	All non-living woody biomass not contained either in the litter, standing, lying on the ground, or in the soil	wood lying on the surface, dead roots, and stumps

Table C-2 Amount of forest biomass by type in Malaysia from the year 1990 - 2010 (Food and Agriculture Organization of the United Nations, 2010)

Type of biomass	Forest Biomass (Million tonnes, dry weight)			
	1990	**2000**	**2005**	**2010**
Above-ground biomass	4,842	6,105	5,767	5,511
Below-ground biomass	1,162	1,465	1,384	1,323
Dead wood	n.a	n.a	n.a	n.a

2.1.2 Oil palm plantation biomass

Oil palm is one of the world's most rapidly expanding equatorial crops. Approximately 85% of world's crude oil palm is supplied by Malaysia and Indonesia (Sulaiman et al., 2011). Malaysia has approximately 5 million ha of palm oil plantation in the year 2011, covered a 15% of total land area (MPOB, 2014). The oil palm has a lifespan about 200 years with the economic life up to 25 years. Peak crop yields are achieved from the age of 9-18, and gradually decline thereafter. Conventionally, a felled oil palm tree, consisting of a large amount of trunk and frond, are often shredded and buried in the field to be turned into organic fertiliser. Nevertheless, due to the cost constraints, some small and private estate holders practise open burning to clear the land, as it is the cheapest mean for land clearing. There are some utilisations of trunks and fronds as source material for plywood production but its uptake is not consistent due to uncertain economic values of the raw materials primarily due to logistic cost. At the time of reporting, it is estimated that 65% of Malaysia's total oil palm trees ranged between the age of 9-20 years, while another 26% is approaching the end of yielding age of 20-28 years old (MPOB, 2014). Approximately 1.3 million ha of Malaysia's oil palm plantation is at the felling age. A felled oil palm tree consists of 70% of trunk, 20.5% of frond, 6.53% of leaflets and 5.03% of others, as shown in Table C-3 (Khalid *et al.*, 1999). Based on the statistical data of old oil palm plantation area, it is estimated that 109 million t of biomass can be obtained from Malaysia old oil palm plantation, with 53.39 million t of trunk, 20.80 million t of frond, and others.

Table C-3 Composition of an old oil palm tree (Khalid *et al.,* 1999)

Biomass composition	Average weight (kg)	Weight percentage (%)	Estimated dried weight (kg/tree)	Dried weight (t/ha)
Trunk	1507.50	70.00	301.50	41.07
Leaflets	145.00	6.53	58.00	7.69
Frond	452.50	20.50	117.70	16.00
Spears	42.75	1.92	9.40	1.28
Cabbage	44.50	2.00	4.50	0.60
Inflorescence	134.50	1.11	6.30	17.56
Total weigh	2217.50	100.00	497.30	84.20

2.1.3 Peatland Biomass

Peatland is a wetland ecosystem with a relatively thick (more than 40 cm) soil layer of organic matter above a mineral substrate (Trettin *et al.*, 2006). Peat soil in Malaysia consists of undecomposed and semi-decomposed woody materials which come from dead leaves and trees that are low in ash content and nutrients. The main composition in peatland is the peat, a heterogeneous mixture of more or less decomposed plant (humus) material that has accumulated in a water-saturated environment and in the absence of oxygen. Peat, especially of temperate peat or boreal peat, is used as a fuel in three main forms:

a) Sod peat - slabs of peat, cut by hand or by machine, and dried in the air; mostly used as household fuel;
b) Milled peat - granulated peat, produced in large scale by special machines; used either as a power station fuel or as the raw material for briquettes;
c) Peat briquettes - small blocks of dried, highly compressed peat; used mainly as a household fuel.

The interest of this study however is focused on the biomass waste particularly from the surface vegetation of peatlands undergoing development or otherwise abandoned.

Box C- 1 Land use and Biomass in Indonesia

Indonesia is rich with variety of vegetation and various of biomass resource, as shown in Figure C-1. The island of Sumatera, Indonesia, consist of 9,680,020 ha of dipterocarp forest, 7,447,358 ha of peat forest, 12,209,475 ha of oil palm plantation, as shown in Table 4.

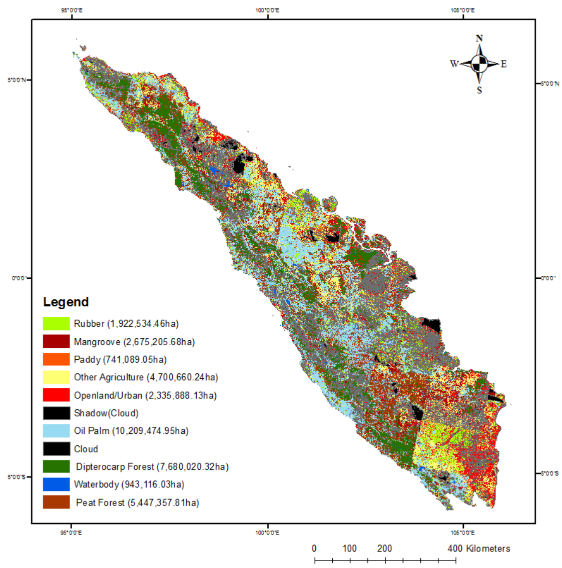


Figure C-1 Land use distribution in Sumatera, Indonesia

Table C-4 Land use in Sumatera in year 2015/2016

Type of Land use	Area (Ha)	Biomass (Mg/ha)	Biomass (Mg)
Dipt Forest	9,680,020	149	1,439,419,021
Peat Forest	7,447,358	225	1,675,655,508
Mangrove Forest	4,675,206	250	1,168,801,419
Oil Palm	12,209,475	89	1,080,538,533
Rubber	2,922,534	2	6,517,252
Paddy	741,089	2	1,482,178
Other Agriculture	6,700,660	2	13,401,320
Non vegetated	3,000,000	-	-
TOTAL	47,376,343		5,385,815,232

In year 2015, it is estimate that approximately 5,385,815,232 Mg of biomass can be obtained, with 1,675,655,508 Mg of biomass from peat forest and 1,080,538,533 Mg of biomass from oil palm plantation.

2.2. Biomass Characteristics

The chemical composition of the forest biomass and oil palm plantation biomass are shown in Table C-5. As there are various types of forest biomass, the woody biomass is used as the representative of biomass. While for the oil palm plantation biomass, the oil palm trunk (OPT) and oil palm frond (OPF) are the main focus for the comparison of biomass characteristic. The properties of empty fruit branch (EFB) are also presented in Table C-5 as the comparison with the other types of biomass. The properties of biomass are compared in the proximate analysis, ultimate analysis, and lignocellulosic content. In the proximate analysis, oil palm frond is found to have the highest moisture content (16.00%) as compared to the trunk and EFB. The highest amount of ash is found in the EFB (18.07%). Forest biomass, which contains various mixed of biomass, is difficult to obtain the data of proximate analysis, but it has very low ash contain. The ultimate analysis measured the elemental contents for carbon, hydrogen, oxygen, nitrogen and sulphur (C, H, O, N, and S). It is valuable indicators to energy processes and gases emissions during combustion of the resource material. The forest biomass showed higher value of C (48.10%) as compared to that of the trunk (40.64%) and frond (44.50%). Comparisons were also made with the elemental composition of the EFB, where the highest amount of H and N are found in 6.44% and 2.18% respectively. In terms of the lignocellulosic content, EFB also has highest amount of cellulose (57.80%), while similar lignin and hemicellulose content of each biomass. The higher heating value (HHV) of the biomass also compared, where EFB has the highest value of HHV with 20.54MJ/kg, while both trunk and frond has slightly lower HHV then the EFB, with 17.27MJ/kg and 17.28MJ/kg respectively.

Table C-5 Properties of biomass

	Forest biomass [a]	**Oil Palm Plantation Biomass**		**Empty Fruit Branch (EFB)** [c, f]
		Oil Palm Trunk [b, c]	Oil Palm Frond [d, e]	
Proximate analysis (wt% dry basis)				
Moisture content	n.a	8.34	16.00	4.68
Volatile matter	n.a	79.82	83.50	76.85
Fixed carbon	n.a	13.31	15.20	5.19
Ash	1.70	6.87	1.30	18.07
Ultimate analysis (wt% dry basis)				
C	48.10	40.64	44.58	46.36
H	5.99	5.09	4.53	6.44
O	45.72	53.12	48.80	38.91
N	n.a	2.15	0.71	2.18
S	n.a	n.a	0.07	0.92
Lignocellulosic content (wt% dry basis)				
Cellulose	45.80	45.90	50.33	57.80
Hemicellulose	24.40	25.30	23.18	21.20
Lignin	28.00	18.10	21.7	22.80
HHV (MJ/kg)	15.00	17.27	17.28	20.54

a. Saidur et al., 2011
b. Nimit et al., 2012
c. Oil palm biomass (www.bfdic.com)
d. Guangul et al., 2012
e. Abnisa et. al., 2011
e. Abdullah and Sulaiman, 2013

Box C- 2 Supply Cost Structure of Biomass Primary Residues in Peninsular Malaysia

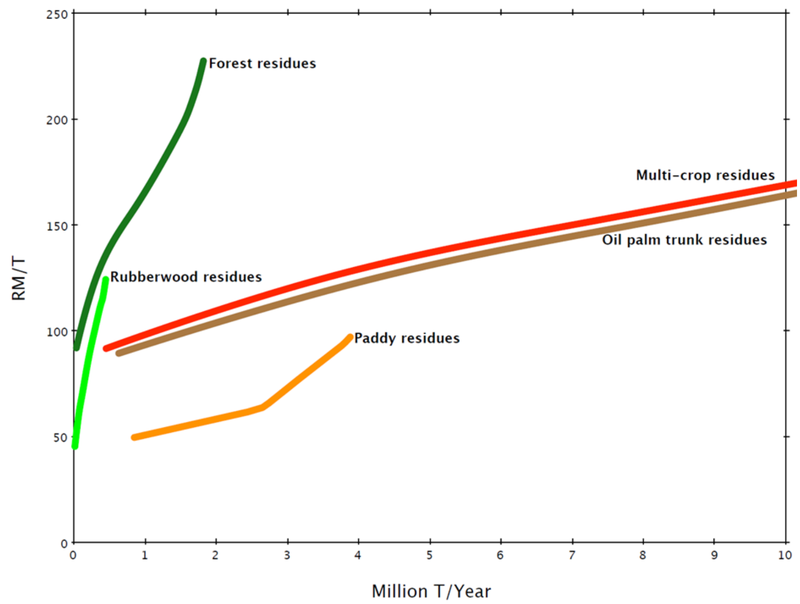


Figure C- 2 Spatial computation and analysis of biomass primary residues supply in Peninsular Malaysia

The figure above shows the result of spatial computation and analysis of biomass primary residues supply in Peninsular Malaysia. The result is taking into account the geographical locations of the biomass, annual residues production, distances (Euclidean) and transport cost. Each cost curve illustrates the biomass supply structure to its minimum cost location. The optimal location for forest residues is at Gua Musang, Kelantan. It has limited annual production of residues of 1.83 million tonnes and has relatively very high supply cost. Rubberwood residues have very little availability of only 0.45 million tonnes per year, its least cost location is in Raub, Pahang. Rice stalk has the most optimal biomass supply if the mill is located in Yan, Kedah. It has the lowest supply cost and significant availability of 3.9 mil tonnes per year. This is due its highest production density among others. Oil palm trunk (OPT) has the highest availability of 17.8 mil tonnes per year with reasonable cost when location of the mill is in Jempol, Negeri Sembilan. Multi-crop is the combination of the four resources and its optimal location is in Temerloh, Pahang. Its cost structure is mainly led by OPT as it constitutes 74% and rice stalk 16%. With the geographical heterogeneity of these resources, it suggests that it is not efficient to have multi-biomass sourcing with single-plant strategy. The better alternative would be to have multi-plant strategy capitalising at its cost-efficient resources, namely rice stalk in Yan, Kedah and OPT in Jempol, Negeri Sembilan.

Source: Adapted from Chu Lee Ong, Juliette Babin, Jia Tian Chena & Jean-Marc Roda. (2016) Designing model for biomass transport cost of biofuel refinery in Malaysia. Unpublished.

2.3 Conversion pathway of biomass to products

Conversion of biomass generated on the forest, fields or plantations could overcome the issue of haze that caused by forest fire. In general, the approaches for transforming biomass resources to products and energy or biofuels involve thermochemical, biochemical, and physical conversion processes. Each of these processes shall be briefly explained as follows.

2.3.1 Thermochemical Conversion

Thermochemical conversion of biomass involves the processing of biomass feedstock at elevated temperatures, and typically yields the following potential products: -

a) Thermal energy from flue gas, to be harnessed to generate steam and power generation; and
b) Upgraded biofuels

The thermochemical conversion technologies encompass direct combustion, pyrolysis and gasification. Whereby the first technology category would result in energy products, the remaining technology categories are associated with biofuel production.

2.3.2 Biochemical Conversion

Biochemical conversion involves biological process that transforms the biomass substrate into value-added products under anaerobic conditions. These conversion routes comprise fermentation and anaerobic digestion (AD), which respectively produce biofuel, biogas and biochemical.

2.3.3 Physical Conversion

The biomass resources could also be directly processed into value-added solid fuels through pre-treatment and physical modifications (i.e. drying, compression, compaction, densification, etc.). The physical processing of biomass is meant to reduce the moisture content, increase the bulk density, and enhance its combustibility or calorific value.

The relationship between these potential biomass conversion processes, biomass inputs (as reviewed in previous section) and the resulting products (i.e. energy products and biofuels) is as depicted in Figure C-2.

3 Conversion Technology for Biomass to Products: based on product value

The product derived from biomass can be categorised into three main types based on the economic value, namely the low value product, medium value product, and high value product, as shown in Table C-6. Low value products, such as compost, require very low investment cost and simple conversion technologies, but the product value is relatively low. Heat and power product from biomass are considered as medium value product while the biofuel and biochemical product require high investment cost and the product value is highest among the three categories.

Table C-6 Types of product derived from biomass

Type of product	Product
Low value product	Compost
Medium value product	Heat and power
High value product	Biofuel and bio-chemicals

3.1 Biomass to Compost (low value product)

Aerobic composting is the most commonly used biological treatment for the conversion of organic portion of waste. It is defined as the biological decomposition and stabilisation of organic substrates under conditions that allow development of thermophilic temperature as a result of biologically produced heat and compost. Figure C-3 illustrates the process of composting. Application of aerobic composting included yard waste, organic portion of biomass, commingled biomass, and co-composting with wastewater sludge (Tchnobanoglous, *et al.*, 1993). The composting of organic fraction of waste under aerobic condition is presented by Equation 1.

$$\begin{array}{c} \text{Organic matter} \\ + \\ O_2 \\ + \\ \text{nutrients} \end{array} \rightarrow \begin{array}{l} \text{new cells} \\ + \text{ resistant organic matter} \\ + CO_2 \\ + H_2O \\ + NH_3 \\ + SO_2 \\ + \text{ heat} \end{array}$$

Equation C- 1 Composting of organic fraction of waste under aerobic condition

According to Equation 1, the composting process of organic matter requires the presence of oxygen and nutrient for the microorganism to undergo the biodegradation of organic matter into smaller molecules. The resistant organic matter, which contains high portion of lignin, is recognised as compost. New cells, CO_2, water, ammonia (NH_3) and sulphate ($SO_2\ ^{2-}$) are the by-products of the process. There are several parameters that are critical to the result of the process and need to be controlled, for instance, moisture content, C/N (carbon to nitrogen) ratio and temperature of composting. Composting process is able to reduce the volume of the organic waste by up to 50%.

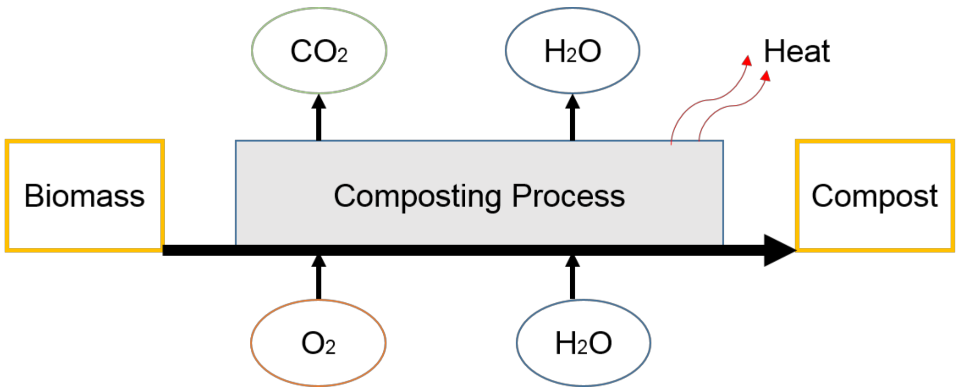


Figure C-3 Illustrated Diagram on the Composting Process (adapted from Ahmad *et al.*, 2007)

Biofertilizer microorganisms incorporated into the biomass compost to produce bioorganic fertilizer or biofertilizer. Examples of biofertilizer microorganisms are N_2 fixing bacteria (Rhizobium spp., Azospirillum spp. Azotobacter spp.), phosphate solubilising microbes (Bacillus spp., Klebsiella spp., Penicillium spp) and plant growth promoting rhizobacteria, (Azotobacter spp., Enterobacter spp.).

Several large plantation companies in Malaysia, e.g. FELDA, FELCRA, and Sime Darby are embarking on their own biofertilizer production, especially for oil palm. Oil palm production has been dependent on chemical fertilizers. Their interest in biofertilizer is partly due to increasing cost of chemical fertilizers, particularly urea, and partly to awareness on green technology for crop production. It is estimated that 60% of cost of production in oil palm are on fertilizers. On top of that, Malaysia is facing infertile soil due to loss of top soil and years of planting on same soil in addition to increasing pest and diseases.

3.2 Biomass to Power generation (medium value product)

Conversions of biomass resources to power and heat require several steps including biomass fuel preparation (pre-treatment, pre-drying, size reduction) and selection of conversion technology.

3.2.1 Biomass Fuel Preparation

Biomass is the main solid waste obtained from forest and waste palm oil. However, due to its characteristics i.e. high moisture content, non-uniform shape and size, and low bulk density (Kaliyan and Morey, 2009), it is difficult to handle, transport, store, and utilise as a fuel (Sokhansanj *et al.,* 2005). In order to reduce industry's operational cost as well as to meet the requirement of raw material for power generation, the biomass requires prior preparation and processing in an efficient manner. Therefore, pre-treatment processes of pre-drying and size reduction is required to improve the efficiency and is usually followed by a pelletising or briquetting process to reduce the biomass bulk density. Biomass shredding and pelletisation processes are further discussed in Sections 3.2.1.1 and 3.2.1.2.

3.2.1.1 Process of Biomass Shredding

Biomass shredding process would enhance the size reduction and convert the larger woody biomass into chips-like particulate for handling purposes, and subsequently create a suitable feed for the production of fuel from biomass. The size reduction process is able to remove the moisture and low-calorific volatiles and partially destruct the biomass constituents (hemicelluloses, cellulose), thus promoting variations in the elemental composition and heating values of the biomass (Dooley *et al.,* 2012). The biomass shredding process is normally conducted on-site where the biomass is collected or produced to ease transportation. Shredded biomass is not suitable for long transportation such as cross-country shipping and for storage as it will decrease the heating performance of the biomass. Biomass shredding is commonly practised for local domestic power plant, as steam boiler does not require high heat energy; shredded biomass is selected due to its low price. However, for furnace boiler which requires higher heat, pelletised biomass is more suitable.

3.2.1.2 Process of Biomass Pelletising

The production of pellet is similar to the briquette, except that the end process of pelletising requires the compressed biomass to pass through a hammer mill to produce a uniform dough-like mass. This mass is fed to a press, where it is squeezed through the holes of the size ranging from 6mm to 8mm of diameter. Due to the high pressure, the increase in the temperature causes the lignin to plasticise slightly, producing a natural "glue" that holds the pellet together as it cools down.

Pelletising is the process of compacting loose organic materials into a higher density and uniform solid fuel. It helps to improve the physical, chemical and combustion properties for direct firing. Pelletised biomass is more favourable for packing and storage. Pelletising is defined as compression of biomass into cylinders with a diameter of 6 to 12 mm, aspect ratio of approximately four, and moisture content below 8% (PiR, 2006). Pelletised biomass has a higher energy density as compared to shredded biomass, resulting in the improvement of material handling (Moran *et al.,* 2004) and providing a renewable fuel source more economical than oil or natural gas. Specifically, in several European Union (EU) countries, Canada, and the US, pelletisation has been a mature technology for biomass-based industrial heat and power generation. Increased application of wood pellets for electricity generation is also evaluated in many Asian countries including China, Korea and Japan (Pirraglia *et al.,* 2010a).

The process as shown in Figure C-4 improves the physical, chemical and combustion properties over those of the raw.

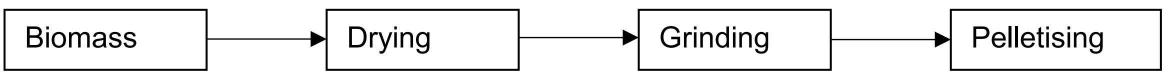


Figure C-4 Process of biomass pelletising

3.2.2 Biomass to Power Conversion Technology

Biomass to power conversion systems fall into two categories, i.e. the direct-fired and gasification systems. The direct-fired category includes stoker boilers, fluidised bed boilers, and co-firing. The gasification category on the other hand includes fixed bed gasifiers and fluidised bed gasifiers. Table C-7 shows different types of biomass conversion technology and specifications.

Table C-7 Summary of Biomass to Power Conversion Technologies (Wright, 2006)

Biomass Conversion Technology	Common Fuel Types	Feed Size (inches)	Moisture Content (%)	Capacity Range (MW)
Stoker grate, underfire stoker boilers	Sawdust, bark, chips, hog fuel, shavings, end cuts, sander dust	0.25 - 2	10-50	4-300
Fluidised bed boiler	Wood residue, peat, wide variety of fuels	↓ 2	↓60	300
Cofiring—pulverised coal boilers	Sawdust, bark, shavings, sander dust	↓0.25	↓25	1000
Cofiring—stoker, fluidised bed boilers	Sawdust, bark, shavings, hog fuel	↓2	10-50	300
Fixed bed gasifier	Chipped wood or hog fuel, shells, sewage sludge	0.25-4	↓20	50
Fluidised bed gasifier	Most wood and agriculture residues	0.25-2	15-30	25

3.2.2.1 Biomass Direct-Firing System

Biomass combustion technologies convert renewable biomass fuels to heat and electricity. At present, the primary approach for generating electricity from biomass is direct firing combustion. This is a widely available commercial technology. The combustion system for electricity and heat production from biomass are similar to most fossil fuel fired power plants. The biomass fuel is burned in a boiler or furnace with excessive oxygen and under high pressure to produce high-pressure steam, composed primarily of nitrogen (N_2), CO_2, water (H_2O, flue gas), oxygen (O_2) and non-combustible residues (Tchnobanoglous *et al.*, 1993). The steam is directed to the Rankine cycle in the steam turbine. The single steam cycle normally produces only electricity, while the cogeneration of steam and electricity requires an extracting steam cycle. Figure C-4 presents the process of direct firing of biomass.

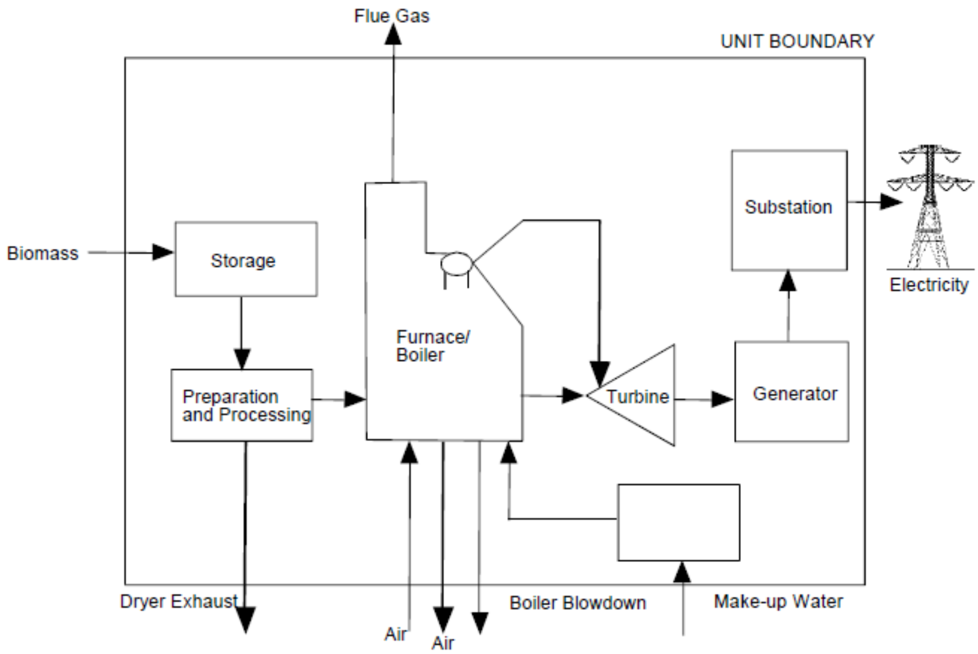


Figure C-5 Direct-combustion of Biomass for Electricity Generation (Brian Williams, 2015)

The following Table C-8 shows the summary of different combustion system, including pile combustion, stoker combustion and fluidised bed combustion.

Table C-8 Summary of combustion system (Kumar Rayaprolu, 2009)

Parameter	Pile Combustion	Stoker Combustion	Fluidised Bed Combustion
a) Grate	Fixed / Stationary Grate	Fixed/ moving grate	No grate
b) Draft conditions	Natural Draft / Forced Draft/ Balance Draft	Forced Draft / Balance draft	Balance draft
c) Combustion	Uniform size of the fuel in the range of 60 to 75mm is desired & % fines should not be more than 20%	Uneven fuel size can be used	Uniform size fuel in the range of 1 to 10mm.
d) Combustion	Difficult to maintain good combustion due to : • Air fuel mixing is not proper • Bed height is in stationary condition resulting in clinker formation • Difficult to avoid air channelling • Due to intermittent ash removal system it is difficult to maintain good combustion	The combustion is better & an improved version of pile combustion. Since most of the fuel is burnt in suspension, the heavier size mass falls on the grate. If the system has a moving grate, the ash is removed on a continuous basis & therefore, the chances of clinker formation are less.	Best combustion takes place in comparison with the other types since the fuel particles are in fluidised state & there is adequate mixing of fuel & air.
e) Boiler efficiency	50 - 60 %	65 - 75%	80 - 82%
f) Bed temperature	1250 - 1350 °C	1000 - 1200 °C	800 - 850 °C
g) Moisture	High moisture leads to bed choking & difficult combustion conditions	Combustion condition not very much disturbed with 4 - 5% increase in moisture	It can handle fuels with high moisture condition up to 45-50% but high

Parameter	Pile Combustion	Stoker Combustion	Fluidised Bed Combustion
			moisture in the fuels is not desirable, & adequate precautions are to be taken up in the design stage itself
h) Maintenance	Not much maintenance problems	Not much maintenance problems	Erosion of boiler tubes embedded in the bed is quite often

Based on the above summary, stoker combustion and fluidised bed combustion are the two most promising options to be considered. The pros and cons for both systems are highlighted in the following Table C-9.

Table C-9 Description of Stoker Combustion and Fluidised Bed Combustion (Bowman et al., 2009)

	Stoker Combustion	**Fluidised Bed Combustion**
A) Combustion Control		
Responsiveness	Slow response	Quick response
Excess air control	Difficult	Possible
B) Fuel Issues		
Applicability to various fuels	Fair	High
Fuel pre-treatment	Generally not necessary	Lumps must be crushed
C) Environmental Factors		
Low sulphur oxide (SOx) combustion	In-furnace desulphurization not possible	High rate of in-furnace desulphurization
Low NOx combustion	Difficult	Inherently low NOx
Appropriate facility size	Small	Medium to large
Cost		
Unit Capital Cost (RM/kg steam)	1633	3379
Total Annual O&M, (RM/1,000 kg Steam)	25	29.5

When a step-grate boiler is used to combust biomass fuel, a steam turbine cycle will be used to generate power. In the steam turbine, the incoming high-pressure steam is expanded to lower pressure, thereby converting thermal energy of high-pressure steam into kinetic energy through nozzles, and then to mechanical power through rotating blades. The different types of steam turbines include backpressure steam turbine and extraction-condensing turbine (see Table C-10).

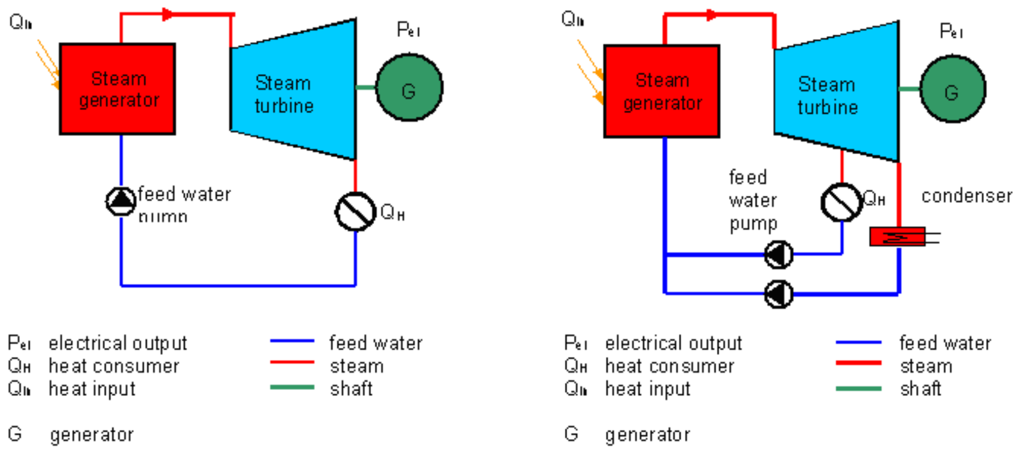


Figure C-6 Steam cycle with Back Pressure Turbine and Extraction Condensing Turbine (Arkadiusz Mysiakowski, 2016)

Table C-10 Comparison between Back-Pressure and Extraction-Condensing Steam Turbines (University of Illinois, 2004)

Cogeneration System	Back-Pressure Turbine	Extraction-Condensing Turbine
Steam extraction	• Hot steam produced in the boiler is expanded down to back pressure (exhaust steam at atmospheric pressures and above) which results from the desired temperature of the process heat. • All steam is condensed by exchanging heat with process stream • The exhaust steam is at low pressure	• A portion of steam can be taken from the extraction point which is at the middle part of the turbine for heat generation • The remaining of steam will condensed at condenser • The exhaust steam can be at either medium or low pressure
Application	• Industry and power supply enterprises (electricity, district heating), (outputs of ~0,5-30 MWel and more) • When a constant amount of heat is required (because of little possibilities of control)	• medium to higher output (~0,5-10 MWel and more) • variable heat and power requirements • For low heat requirements, it can be used like a conventional condensing turbine • Various other operational modes are possible due to valve control
Heat to power ratio (kWth/kWe)	4.0 - 14.3	2.0 - 10.0
Power Output (% of fuel input)	14 - 28	22 - 40
Overall efficiency	84 - 92	60 - 80

3.2.2.2 Gasification

Gasification is a thermal conversion of solid-phase biomass into synthesis gas or syngas as the main product and residual char as by-product, in the presence of gasifying carrier (i.e. air, steam, carbon dioxide, hydrogen, etc.) with low levels of oxygen (Molino *et al.*, 2015). This thermochemical conversion process needs heat input for its initiation, and the necessary heat energy may be internally generated as in auto-thermal gasification process or externally supplied as in allo-thermal gasification process. For auto-thermal gasification process, four (4) main stages are involved, namely partial oxidation, drying, pyrolysis, and reduction (McKendry, 2002b).

The major product of gasification process, known as syngas or producer gas, is constituted mainly from hydrogen and carbon monoxide, and partially by carbon dioxide, water, methane, hydrocarbon gases (Ciferno and Marano, 2002), and minor impurities (i.e. ammonia, hydrogen sulphide, and hydrogen chloride) (Molino *et al.*, 2015). Nitrogen may also be present in the synthesis gas (but would be more appropriately addressed as producer gas in this context) if air is supplied as gasifying agent (Wilson *et al.*, 2013). Its presence actually decreases the calorific value of syngas to the range of 4 - 6 MJ/m^3, whereas the syngas resulted from gasification process driven by steam or oxygen gas would be more combustible with higher calorific value range of 10 - 20 MJ/m^3 (Ciferno and Marano, 2002). The composition, energy content, and combustion characteristics of syngas depend on the operating conditions (Wu *et al.*, 2014), gasifier technology type (Liu and Ji, 2013), and fuel feedstock type (Schmid *et al.*, 2012). Woody biomass resources containing cellulose, hemicellulose and lignin, such as wood wastes, wood logs and straws are usually compatible with gasification process (Ciferno and Marano, 2002).

The common gasification technologies include fixed-bed and fluidised bed gasifiers. The advantages and disadvantages of these gasification technologies are as summarised in Table C-11.

Table C-11 Descriptions and Temperature Ranges of Gasification Stages (E4tech, 2009)

Gasification Stage	Description	Temperature Range (°C)
I. Partial Oxidation	• Oxidation of carbon and hydrogen elements of biomass by limited oxygen to form carbon dioxide, carbon monoxide, and water; • Important to supply heat for the remaining stages	1,000 - 1,500
II. Drying	• Removal of moisture content via vapourisation induced by boiling process	↓ 200
III. Pyrolysis	• Thermal breakdown of carbon-containing materials in biomass to produce pyrolysis gas, condensable tar, and char	200 - 600
IV. Reduction	• Reaction of gas mixture (resulted from partial oxidation and pyrolysis) with char (i.e. reducing agent) to form synthesis gas (i.e. syngas)	600 - 1,000

3.3 Biomass to Biofuel/Biochemical Technology

Lignocellulosic biomass is an inexpensive and abundant renewable resource which offers great potential for conversion to ethanol. It stores energy from sunlight in its chemical bonds and includes the agricultural residue, forestry residue, yard waste, wood products, and animals. Typically, lignocellulosic biomass is constituted from cellulose (32-47%), hemicelluloses (19-27%) and lignin (5-24%) (Liu *et al.,* 2014). In the biochemical conversion lignocellulosic biomass to ethanol, four major processes, pre-treatment, hydrolysis, fermentation, and distillation are needed as depicted in Figure C-7 (Limayem & Ricke 2012).

Maximum valorisation of biomass can be achieved through its conversion to biofuels and biochemical and the list of potential biochemical has been reported in various review papers (Isikgor and Becer, 2015; Werpy and Peterson, 2004). The conversion of lignocellulosic biomass to biofuels and biochemical follows similar routes consisting of pre-treatment, hydrolysis, microbial conversion, and followed by purification. While the process of conversion to biofuels in the form of bioethanol has been commercially established, the processes for conversion to other biofuels such as butanol and biochemical are not commercially available at the present time.

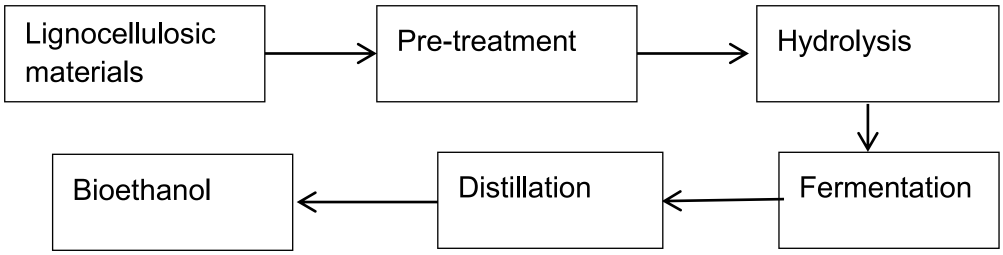


Figure C-7 A generic cellulosic ethanol production process (Limayem & Ricke 2012).

3.3.1 Routes of bioethanol synthesis from biomass

3.3.1.1 Pre-treatment overview

Pre-treatment is required to disrupt the lignin outer layer and expose the carbohydrates for hydrolysis to produce monomeric sugars compatible for fermentation (Chang and Holtzapple, 2000). It may encompass physical (i.e. crushing, pulverisation, etc.) and thermo-chemical processes, optionally coupled with biological pre-treatment (Yang and Wyman, 2008). It shall be noted that biochemical pre-treatment is necessary for reducing biomass recalcitrance (Zhu *et al.*, 2010) and optimising surface area of contact between cellulose (substrate) and cellulase (Zhu *et al.*, 2009). A schematic pre-treatment diagram is shown in Figure C-9 and effective strategies have been elucidated previously (Singh *et al.*, 2014). Classification of pretreatment are found in Figure C-9 and the methods are summarised in Table C-12.

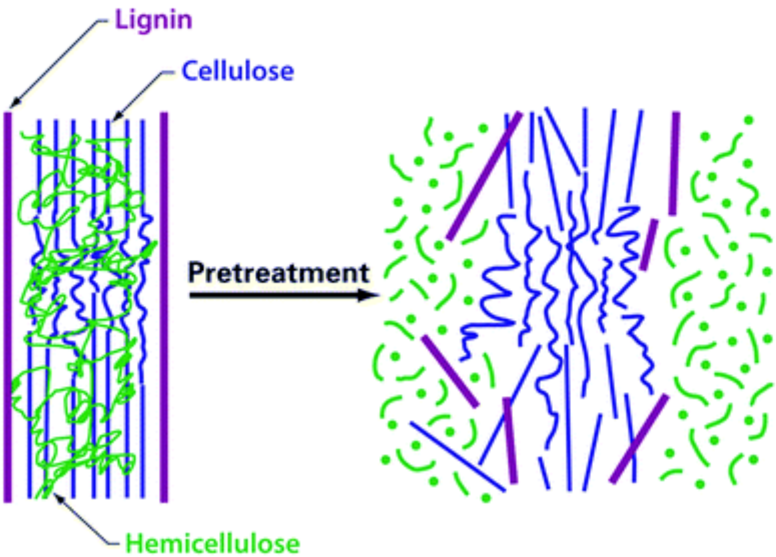


Figure C-8 Schematic of pre-treatment effect on lignocellulosic biomass

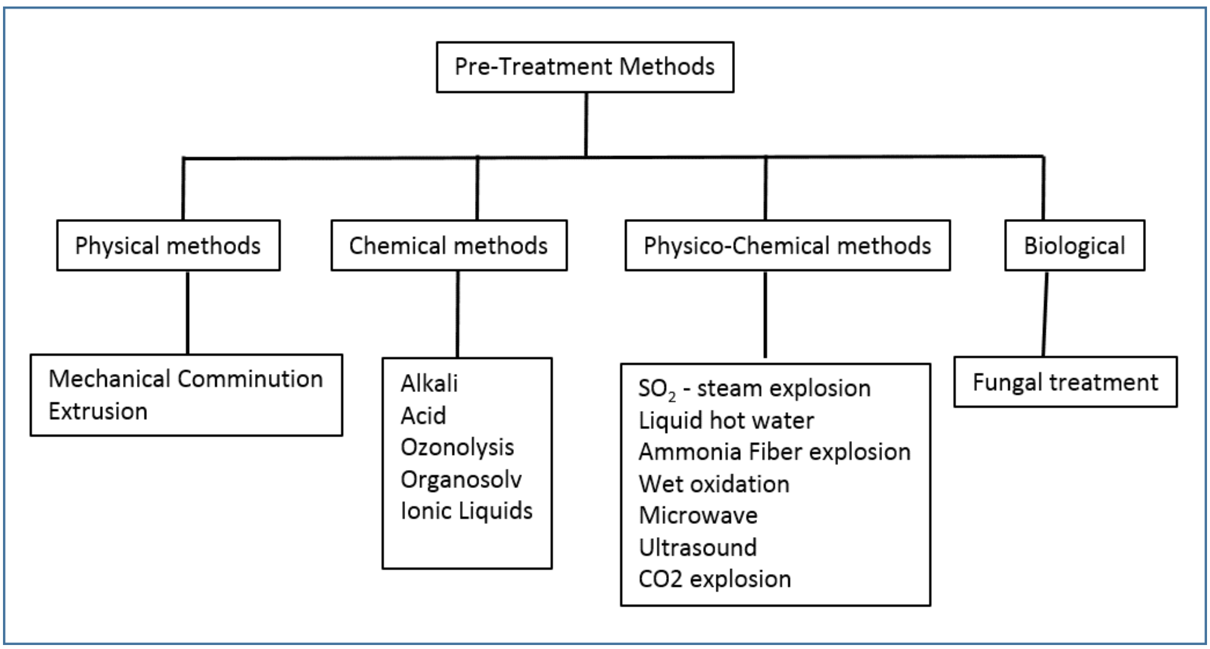


Figure C-9 Different pre-treatment methods

Table C-12 Pre-treatment processes of lignocellulosic materials (Taherzadeh & Karimi 2008)

Pre-treatment method	Processes	Possible changes in biomass	Notable remarks Selected
Physical pre-treatments	Processes Milling: • Ball milling • Two-roll milling • Hammer milling • Colloid milling • Vibro energy milling Radiation: • Gamma ray • Electron-beam • Microwave Others: • Hydrothermal • High pressure steaming • Expansion • Extrusion • Pyrolysis	• Increase in accessible surface area and pore size • Decrease in cellulose crystallinity • Decreased extent of polymerisation	• Most of the methods are highly energy-demanding • Most of them cannot remove the lignin • It is preferable not to use these methods for industrial applications • No chemicals are generally required for these methods
Chemical and physico-chemical pre-treatments	Explosion: • Steam explosion • Ammonia fibre explosion (AFEX) • CO2 explosion • SO2 explosion Alkali: • Sodium hydroxide • Ammonia • Ammonium Sulphite Acid: • Sulfuric acid • Hydrochloric acid • Phosphoric acid Gas: • Chlorine dioxide • Nitrogen dioxide • Sulphur dioxide Oxidising agents:	• Increase in accessible surface area • Partial or nearly complete delignification • Decrease in cellulose crystallinity - Decrease in extent of polymerisation • Partial or complete hydrolysis of hemicelluloses	• These methods are among the most effective and include the most promising processes for industrial applications • Usually rapid treatment rate • Typically need harsh conditions • There are chemical requirements

Pre-treatment method	Processes	Possible changes in biomass	Notable remarks Selected
	• Hydrogen peroxide • Wet oxidation • Ozone		
	Solvent extraction of lignin: • Ethanol-water extraction • Benzene-water extraction • Ethylene glycol extraction • Butanol-water extraction • Swelling agents		
Biological pre-treatments	• Fungi and actinomycetes	• Delignification • Reduction in degree of polymerisation of cellulose • Partial hydrolysis of hemicellulose	• Low energy requirement • No chemical requirement • Mild environmental conditions • Very low treatment rate • Did not consider for commercial application

3.3.1.2 Hydrolysis

Hydrolysis refers to the processes that convert the polysaccharides into monomeric sugars and its completeness determines the success of a pre-treatment operation (Chadel *et al.*, 2007; Gamage *et.al*, 2010). There are two different types of hydrolysis processes (Limayem and Ricke, 2012), namely acid hydrolysis (Xiang *et al.*, 2003) and enzymatic hydrolysis (Yang *et al.*, 2011).

Acid hydrolysis is considered to be the most practical approach to produce high yields of simple sugar, but suffers from the disadvantage of extensive acid requirement, costly acid recycling and undesirable degradation products which renders it commercially less appealing (Hamelinck *et al.*, 2005; Sun and Cheng, 2002).

The success of enzymatic hydrolysis is fundamentally underscored by the efficient pre-treatment which increases the porosity of the lignocellulosic substrate, making the cellulose more accessible to celluloses and improving the enzymatic digestibility of the substrate. The popular industrial-grade celluloses from the fungus *Trichoderma reesei* have a proven efficiency and productivity. Other common enzymatic products tailored for enzymatic hydrolysis process include β-glucosidase, endoglucanases and exoglucanases (Limayem & Ricke, 2012). Advances in enzyme-based technology for ethanol production have been substantial over the years, and as a result, ethanol production costs have been reduced considerably (Wyman 1994). Figure C-10 shows a proposed mechanism for cellulose amorphogenesis/depolymerisation by cellulases.

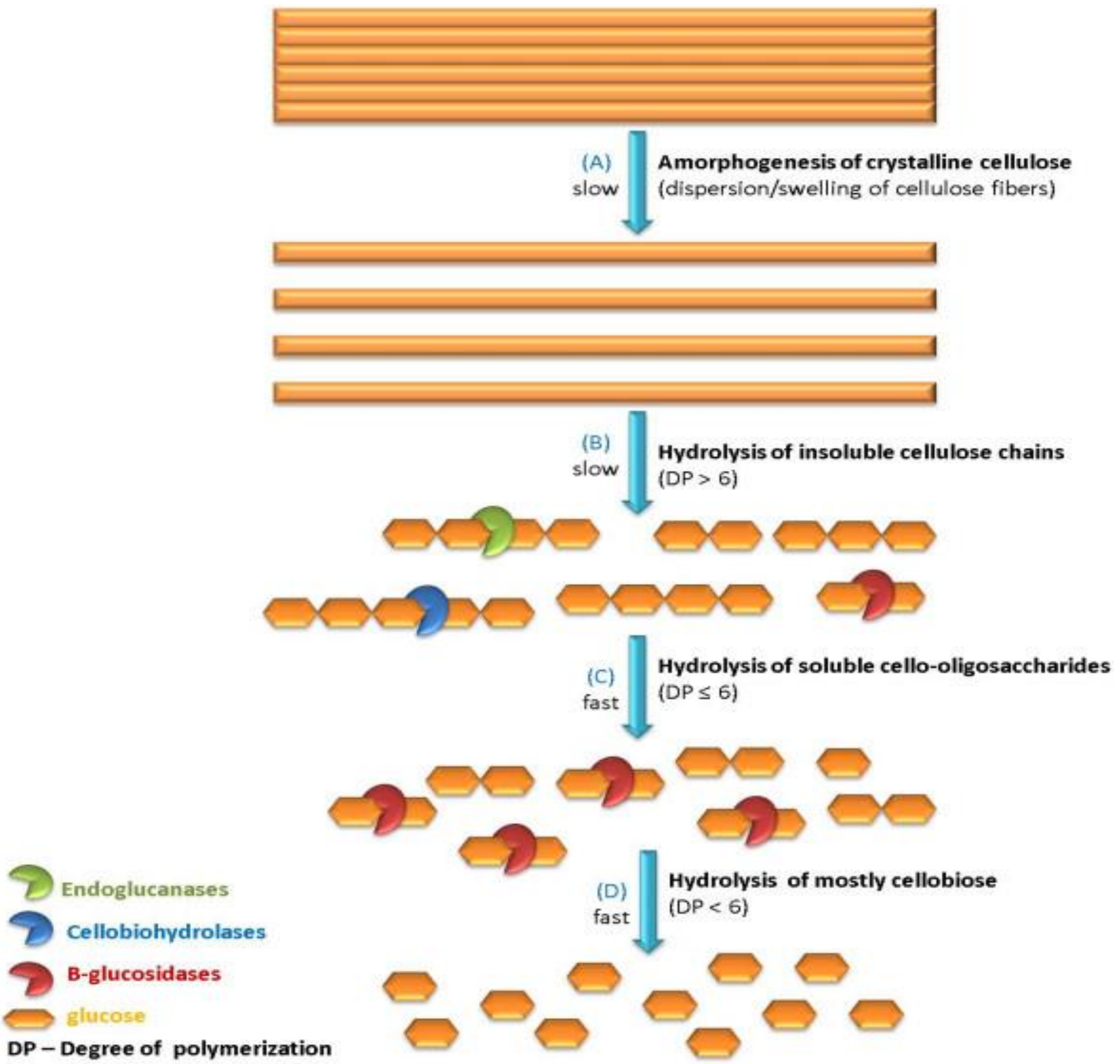


Figure C-10 Proposed mechanism for cellulose amorphogenesis/depolymerisation by celluloses (Arantes and Saddler, 2010)

The fermentable sugars obtained from hydrolysis is then fermented into ethanol by ethanol producing microorganisms, which can be either naturally occurred or genetically modified (Zheng, Pan & Zhang, 2009).

3.3.1.3 Fermentation

The monosaccharides formed by the hydrolysis process are fermented to produce ethanol. Industrial yeasts such as *S. cerevisiae* have established proven track records with high yields in the brewery and wine industries, and its advantages and operating parameters have been extensively discussed (Hahn-Hagerdl *et al*, 2007; Limayem and Ricke, 2007). However, wild *S.cerevisae* is capable of fermenting only C6 hexoses which makes it incompatible for saccharification of a large proportion of hemicellulosic biomass mainly constituted by pentose sugars such as D-xylose (Martin *et al.*, 2002). Moreover, an optimal fermentative microorganism should have tolerance for high ethanol concentration and the presence of chemical inhibitors derived from pre-treatment and hydrolysis processes. In response to such limitation, genetically engineered microorganisms have been extensively employed and capable of concurrently fermenting pentose and hexose sugars without producing significant amount of toxic end-products. Table C-13 compares potential microorganisms for fermentation of lignocellulosic biomass materials (inclusive of bacteria, yeasts and fungi), which have the potential to be developed for improving productivity and revenue in large-scale alcohol industries (Limayem & Ricke, 2012).

In addition, a simultaneous saccharification and fermentation (SSF) process has been developed to enable parallel hydrolysis and fermentation reactions in one single reactor, therefore minimising product inhibition and operational expenditure. However, SSF processes tend to compromise on yields due to different operating temperatures of the hydrolysis and fermentation processes.

Table C-13 Advantages and drawbacks of potential organisms in lignocellulosic-based bioethanol fermentation

Species	Characteristics	Advantages	Drawbacks
Saccharomyces cerevisiae	Facultative anaerobic yeast	• Naturally adapted to ethanol fermentation • High alcohol yield (90%). • High tolerance to ethanol (up to 10% v/v) and chemical inhibitors • Amenability to genetic modifications	• Not able to ferment xylose and arabinose sugars • Not able to survive high temperature of enzyme hydrolysis
Candida shehatae	Micro-aerophilic yeast	• Ferment xylose	• Low tolerance to ethanol • Low yield of ethanol.

Species	Characteristics	Advantages	Drawbacks
			• Require micro-aerophilic conditions • Does not ferment xylose at low pH
Zymomonas mobilis	Ethanologenic Gram-negative bacteria	• Ethanol yield surpasses S. cervesiae (97% of the theoretical) • High ethanol tolerance (up to 14% v/v) • High ethanol productivity (five-fold more than *S. cerevisiae* volumetric productivity) • Amenability to genetic modification • Does not require additional oxygen	• Not able to ferment xylose sugars • Low tolerance to inhibitors • Neutral pH range
Pichia stiplis	Facultative anaerobic yeast	• Best performance xylose fermentation • Ethanol yield (82%) • Able to ferment most of cellulosic-material sugars including glucose, galactose and cellobiose • Possess cellulase enzymes favourable to SSF process	• Intolerant to a high concentration of ethanol above 40 g/L • Does not ferment xylose at low pH • Sensitive to chemical inhibitors • Requires micro-aerophilic conditions to reach peak performance • Re-assimilates formed ethanol
Pachysolen tannophilus	Aerobic fungus	• Ferment xylose	• Low yield of ethanol. • Require micro-aerophilic conditions • Does not ferment xylose at low pH
Esherichia coli	Mesophilic Gram-negative Bacteria.	• Ability to use both pentose and hexose sugars • Amenability for genetic modifications	• Repression catabolism interfere to co-fermentation • Limited ethanol tolerance • Narrow pH and temperature growth range • Production of organic

Species	Characteristics	Advantages	Drawbacks
			acids • Genetic stability not proven yet • Low tolerance to inhibitors and ethanol
Kluveromyces marxianus	Thermophilc yeast	• Able to grow at a high temperature above 52 °C • Suitable for SSF process • Reduces cooling cost • Reduces contamination • Ferments a broad spectrum of sugars • Amenability to genetic modifications	• Excess of sugars affects its alcohol yield • Low ethanol tolerance • Fermentation of xylose is poor and • leads mainly to the formation of xylitol
Thermophilic bacteria: • **Thermoanaerobacterium** • **Saccharolyticum** • **Thermoanaerobacter** • **Ethanolicus Clostridium** • **Thermocellum**	Extreme anaerobic bacteria	• Resistance to an extremely high • Temperature of 70°C • Suitable for SSCombF Processing • Ferment a variety of sugars • Display cellulolytic activity • Amenability to genetic modification	• Low tolerance to ethanol

3.4 Commercialisation of Biomass to Bioethanol technology

In contrast to first generation bioethanol, lignocellulosic raw materials are more abundant and generally considered to be more sustainable. However, the process is longer as the biomass need to be broken down (hydrolysed) into simple sugars prior to fermentation as described above. Due to research and investments made across the globe, second generation, cellulosic bioethanol is now being produced on commercial scale in Europe, US and Brazil. Figure C-11 shows the example of the commercialised ethanol production plant in Italy, beginning 2013 (Melsen, 2015).

Figure C-11 Commercialised ethanol production plant in Italy since the year 2013

Almost, if not all of the plants use the enzymatic hydrolysis followed by fermentation process to convert cellulose to ethanol using enzymes produced by known enzyme suppliers such as Novozyme and Genencor. The consortium of enzymes used is able to convert the hemi-cellulose and cellulose to C5 and C6 sugars. Subsequently, engineered yeast which are able to convert C5 and C6 sugars into ethanol are used in the fermentation process to achieve higher yields and productivity (European Biofuels Technology Platform, n.d.).

It is worth noting that in December 2015, Abengoa ceased production at its Hugoton plant, due to financial difficulties where in November 2015, Abengoa announced that it was trying to reorganise over USD9 billion in debts. This report, therefore, will look at debt: equity analysis in the case study in Section 4 to determine financial sustainability.

Box C- 3 Capital Cost Estimation for Biorefinery Plant

Capital cost estimation of a biorefinery plant is essential before injection of any investment. A design engineer is able to make preliminary cost estimation of a biorefinery plant based on early design states of the plant. There are several methods developed to perform and estimate total plant cost within ±50% accuracy for preliminary studies. In this context, cost curve method is used to give an approximate capital cost data for various licensed processes. The capital cost of a plant can be related to capacity by the Equation C-2 below:

$$C_2 = C_1 \cdot \left(\frac{S_2}{S_1} \right)^n$$

Equation C- 2 Capital cost of a plant

Where $C2$ = Capital cost of the plant with plant capacity $S2$

$C1$ = Capital cost of the plant with plant capacity $S1$

For petrochemical processes, exponent n is set at 0.7, for specialty chemical and pharmaceuticals manufacture, exponent n is set at 0.4 to 0.5, for chemical industry, exponent n is usually set at 0.6. The equation is commonly known as the "six-tenths rule". Exponent n is equal to 0.6 can be used to get rough estimation of the capital cost of plant when there is no sufficient data available.

Economy of Scale

$$\frac{C_2}{S_2} = aS_2^{\,n-1}$$

Equation C- 3 Economy of Scale

Exponent n is always less than one. There is a correlation between the equation and that larger plants tend to cost lower to construct per unit of product produced. As n-1 is less than zero, the capital cost per unit of fuel decreases as S_2 increases. Essentially, smaller capital cost per unit of product produced allows the refinery plant owner to set their product with a higher profit margin yet still recover their capital investment. The advantage is known as an economy of scale.

4 Case Studies – economic potential of biomass-to-resources

Conversion of biomass on the field in forest or plantation into value-added product such as power and ethanol can potentially play a role in an effort to reduce the resulting haze conditions from slash and burn practices. There are competing uses for biomass resources because of their economic and environmental value for a variety of purposes. As mentioned in Sections 2 and 3, biomass material can potentially be used to generate power, heat, steam, and bioethanol, which potentially offer high economic returns to the farmers.

To explore the economic potential of biomass-to-resources, two case studies on biomass-to-power and biomass-to-ethanol are incorporated in this section with the suggested feedstock capacity of 2000t of biomass daily. Net present value economic analysis, with equity and debt corporate financing method, is applied in the case studies to analyse the economic profitable levels of biomass-to-resources.

Economic conversions of biomass range from low investment and low returns biofertilizer to high investment and high returns biochemicals. Biofertilizers are economical only when the biomass residues are readily available for conversion without additional transportation costs such as EFB from palm oil mills. Biopellets can command a higher price, but only if exported to energy deficient countries. It is not economical for local consumption due to the abundance of biomass available locally and that extra costs are required for the pelletising process. Biochemicals on the other hand are not fully commercialised yet. Most of the produced biochemicals are still in piloting stage, hence the lack of data available for the purpose of this study. Thus, this report focuses into the economic potential of biomass-to-power and biomass-to-ethanol conversions.

Box C- 4 Cost Estimation of Biorefinery Plant in Peninsular Malaysia 1

The order of magnitude estimates of the capital cost for several refinery plants are calculated using cost curve method. Figure C-13 shows the graph of capital cost of plant versus capacity of plant from various refinery plants with different conversion processes. Capital cost data of each plant is escalated from 2003 to 2014. Location factor is added to capture the real scenario in Malaysia.

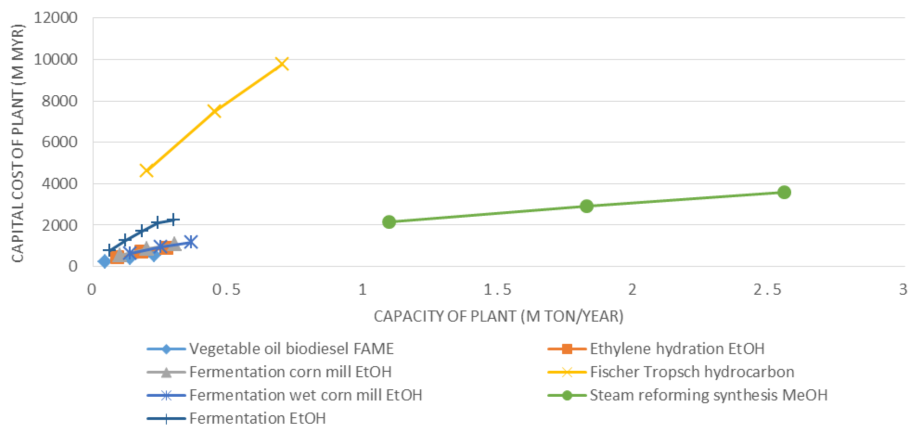


Figure C- 12 Graph of capital cost of plant versus capacity of plant

The Figure C-14 below shows that even in Malaysia, similar economy of scale applies to various biorefinery processes. Further calculation can be done as shown below:

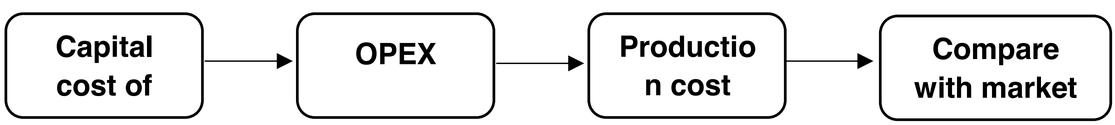


Figure C- 13 Further calculation for cost estimation of biorefinery plant

At preliminary design state of plant, no design information other than the production rate is required. Cost curve method is the fastest way to get a rough estimation of capital cost of a plant.

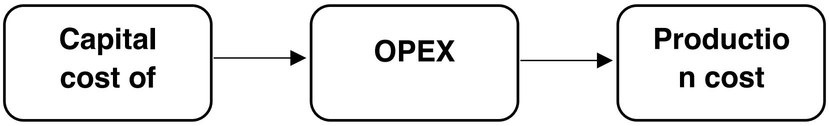
4.1 Biomass to power generation

Malaysia starts utilised biomass to power generation in the year 2003, where a 7.5 MW integrated biomass co-generation plant was established in Sahabat, Lahad Datu, Sabah by the Felda Global Ventures Holdings Bhd (FGV). The power plant used EFB as the feedstock, generate heat and power for demands within the company including the CPO refining , kernel crushing plant, hotel, office and residential. The project is the first Clean Development Mechanism (CDM) Project in Malaysia which is encouraged by the government to invest R&D efforts and to study the feasibility of applying the model throughout the country's industrial sector. With the investment cost of RM38 million, the biomass power plant is successful reduced 377,902 t of CO_2 emission by end of 2012 (CDM, 2006).

Most of the current applications of biomass to power are focused in utilisation of EFB due to its high HHV content and abundant of feedstock from palm oil mill. Up to date, there is no utilisation of forest biomass or oil palm plantation biomass for power generation in Malaysia. Nevertheless, the forest and oil palm plantation biomass are proved to have similar HHV content as the EFB (20 MJ/kg compared to 17MJ/kg) and thus could be a potential source of feedstock for power generation.

Box C- 5 Cost Estimation of Biorefinery Plant in Peninsular Malaysia 2

In this case study, cost curve method is used to estimate the capital cost of a biorefinery plant. Location of plant is assumed to be in Yan, Kedah with paddy and oil palm trunk (OPT) as its respective feedstock.



**Assumption: Feedstock cost comprised of 80% of the total operating cost*

With the estimation of capital cost of plant, operational cost is obtained as well as the relative production cost of plant. Results were plotted as shown in Figure C-15 below:

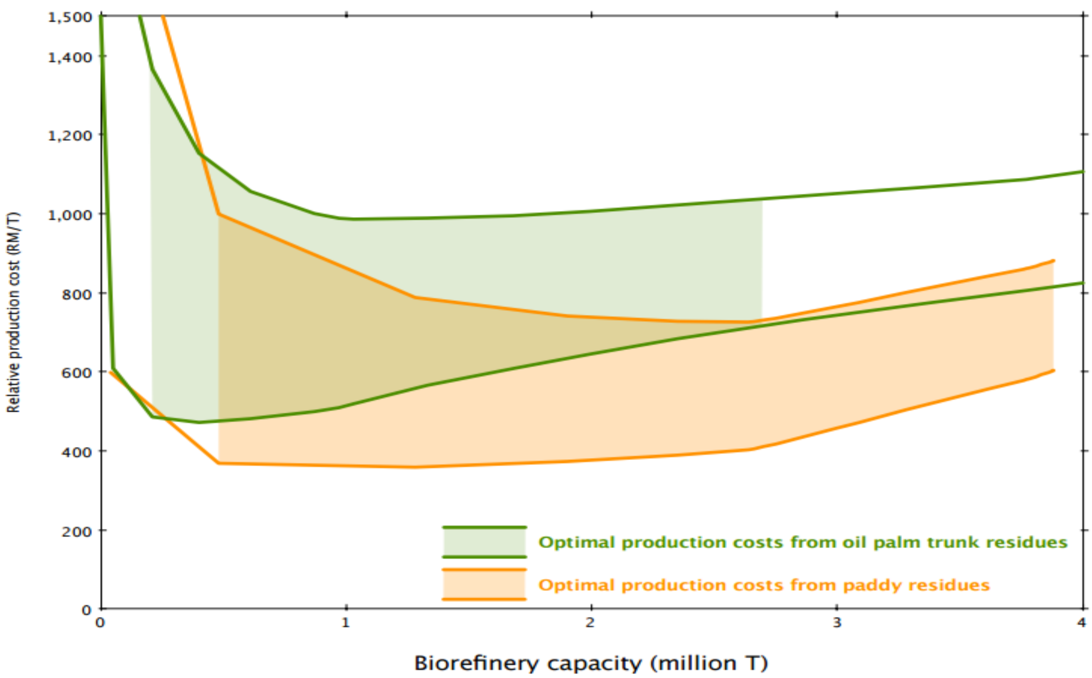


Figure C- 14 Optimal production costs from oil pal trunk residues and paddy residues

Initial finding suggested that paddy is highly available in Yan, Kedah as compared to OPT. Result above visualised the optimal production cost of biorefinery plant in single location with two different feedstocks. When paddy is used as the feedstock, with the capacity of plant in the range of optimal production cost from paddy, it gives a better promising production cost. This is because production cost of plant is highly dependent on the location factor. Economy of scale will be achieved if the biorefinery plant located at an optimal location with high availability of specified feedstock. It is concluded that high variability of production cost in Peninsular Malaysia is corresponding to the location of the biorefinery plant due to geographical heterogeneity of biomass feedstocks.

Source: Chen, J.T., Ong, C.L, Roda, J.M., Centre of Excellence of Biomass Valorization for Aviation, CIRAD-UPM-AMIC (2016)

This report presents the economic potential using 2,000t/d forest and oil palm plantation biomass (OPF and OPT) as the feedstock for power generation with main focus on electricity production. The proposed technology is a 27MW capacity direct combustion system with a 76% efficiency comprising of a pre-treatment drying system, fluidised bed boilers for conversion of biomass to heat and steam, and generation of electricity through extraction-condensing turbine. The biomass feedstock with an assumed calorific value of 15.82MJ/kg with 16% moisture content (dry basis) (Fiseha *et al.,* 2012). The direct combustion technology has a 30-year plant life with investment cost of USD900/kW and USD1050/kW for boiler and turbine respectively. The process, costing and financing information are presented in Table C-14. The costing information was obtained through personal interview with a local biomass-to-power industry stakeholder while the financing data are adopted from NREL report (Humbird et al., 2012).

Table C-14 Parameters for a case study of 2000t/d of biomass-to-power plant

Parameters	**Unit Value**	**Total Value**
Process Information		
Plant life		30 years
Efficiency		76%
Feedstock	2,000 tonnes/d	730,000 tonnes/y
Electricity Production		236,520,000 kwh/y
Heat production		3,524,129 tonnes/y
Costing Information		
Feedstock cost		
Transportation costs	USD10/tonne	USD7,300,000
Harvesting and collection cost	USD10/tonne	USD7,300,000
Pre-processing cost	USD5/tonne	USD3650000
Investment cost of boiler	USD900/kW	USD24,300,000
Investment cost turbine	USD1050/kW	USD28,350,000
Fixed capital	USD3000/kW	USD81,000,000.00
Variable cost		USD1,111,644.00
Operation cost	USD150/kW	USD4,050,000.00
Electricity price	USD0.07/kWh	USD16,556,400.00
Heat price (by-product)	USD12.65/tonne	USD44,575,375
Financing information		
Discount rate		4.1%
Plant depreciation DB		150%
Plant recovery period		20 y
Corporate tax rate		25%
Loan - terms loan APR		5.0%
Loan period		10 y
Construction period		3 y
First 12 months' expenditures		8%
Next 12 months' expenditures		60%
Last 12 months' expenditures		32%
Working capital (% of fixed capital investment)		5%

Start-up time		3 month
Revenues during start-up		50%
Variable costs incurred during start-up		75%
Fixed costs incurred during start-up		100%
BNM Government Securities Yield		4.0%

Using the net present value (NPV) economic analysis, the correlation between the minimum electricity production cost and the equity financing is presented in Figure C-12. Minimum electricity product cost ranged from USD0.23/kWh to USD0.19/kWh with variations of equity financing share of 30% to 70%. The minimum product cost is consider high even with the equity financing adoption as compared to the current feed-it-tariff (FiT) incentive of USD0.10/kWh.

The case study is repeated with different capacities (2000t/d, 1000t/d, and 500t/d), and the results are plotted in Figure C-12. It can be seen that there is only a marginal reduction in the minimum electricity price (ranged from USD0.24/kWh to USD0.19/kWh) due to economy-of scale capacity increment. This is due to the high fixed investment cost (approximately USD3000/kW), while the current FiT scheme is relatively low. The low FiT scheme renders the biomass-to-power to be less competitive at the current power industry market.

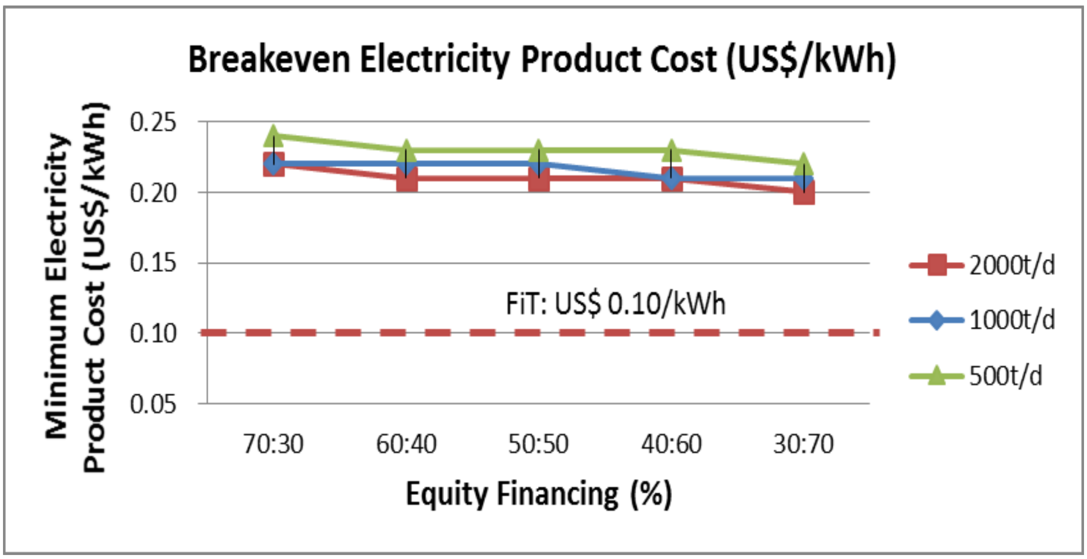


Figure C-15 Breakeven of electricity selling price for biomass-to-power in Malaysian context

4.2 Biomass to ethanol generation

Maximum valorisation of biomass can be achieved through its conversion to biofuels such as ethanol as presented in Section 3. The conversion of lignocellulosic biomass to biofuels and biochemical follows similar routes consisting of pre-treatment, hydrolysis, microbial conversion, followed by purification. While the process of conversion to biofuels in the form of bioethanol has been commercially established, the processes for conversion to other biofuels such as butanol and biochemical are not commercially available at the present time. There are a number of processes in the pilot or pre-commercialisation stage all over the world (Becker et al., 2015) and it is predicted that commercialisation of a few biochemical processes will happen in the next 5 years. Within this scenario, this report will focus on describing the process involved in the production of bioethanol as well as its economic evaluation in the Malaysian context to serve as a first estimate for a more rigorous evaluation.

The case study for biomass to bioethanol presents the economic potential using 2000t/d biomass as the feedstock. The proposed technology is enzymatic hydrolysis followed by fermentation with the cellulosics content in biomass of 70% and conversion yield of the cellulosics to C5 and C6 sugar of 95%. The fermentation process is using high substrate tolerant recombinant yeast capable of converting 30% fermentable C5 and C6 sugars to 15% ethanol. The technology has a 30-year plant life with the total capacity cost of USD1,094,065,600.00. The major variable cost is assumed to be the enzyme cost of about USD0.6/gal of ethanol. Table C-15 presents the process information and costing of the biomass-to-bioethanol.

Table C-15 Parameters for a case study of 2000t/d of biomass-to-ethanol plant

Parameters	Unit Value	Total Value
Process Information		
Plant life		30 years
Conversion efficiency		
Celloluse		70%
C5 and C6 sugars		95%
Feedstock	2000 tonnes/d	730000 tonnes/y
Ethanol Production		65,887,070.60 gal/y
Costing Information		
Land cost	USD2.75/sf	USD1,497,636
Feedstock cost		
Transportation costs	USD10/tonne	USD7,300,000
Harvesting and collection cost	USD10/tonne	USD7,300,000
Capacity cost		USD1,094,065,600.00
Operation cost (Enzyme)	USD0.6/gal	USD39,532,242.36
Ethanol price	USD1.47/gal	
Financing information		
Discount rate		4.1%
Plant depreciation DB		150%
Plant recovery period		20 y
Corporate tax rate		25%
Loan - terms loan APR		5.0%
Loan period		10 y
Construction period		3 y
First 12 months' expenditures		8%
Next 12 months' expenditures		60%
Last 12 months' expenditures		32%
Working capital (% of fixed capital investment)		5%
Start-up time		3 month
Revenues during start-up		50%
Variable costs incurred during start-up		75%
Fixed costs incurred during start-up		100%
BNM Government Securities Yield		4.0%

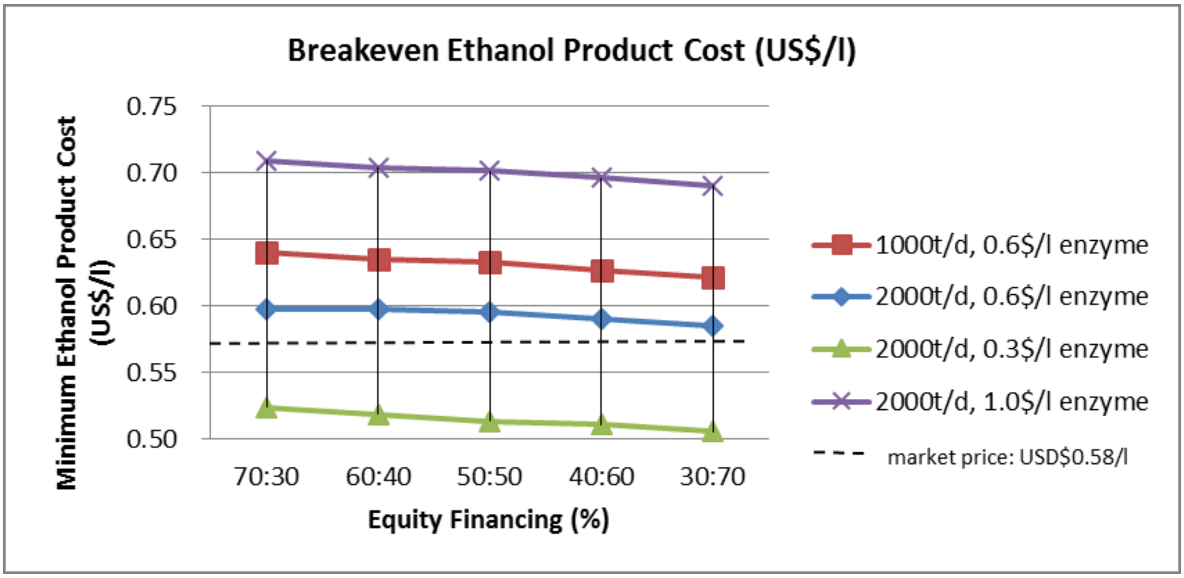


Figure C-16 Breakeven of ethanol selling price for biomass-to-ethanol in Malaysian context

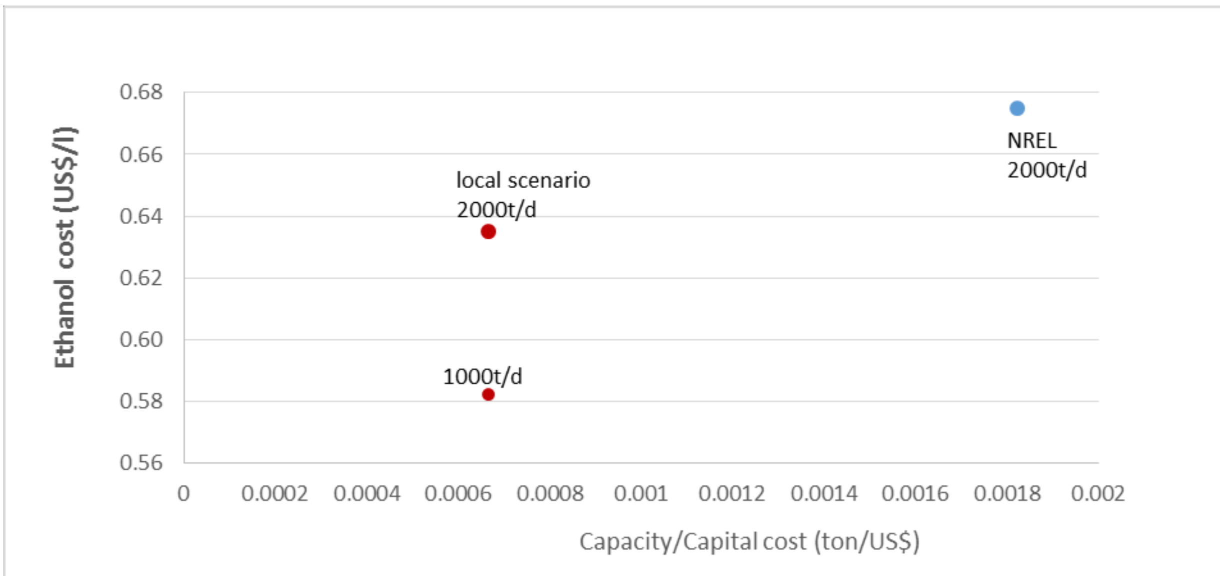


Figure C-17 The price of ethanol with different capacity and capacity cost

Table C-16 Ethanol production cost ($/l) reduction by improving the debt: equity ratio or interest rate

Debt:Equity ratio	Interest Rate		
	8%	**5%**	**3%**
95:5	0.77	0.61	0.52
70:30	0.73	0.60	0.53
60:40	0.71 (0.57[a])	0.60	0.53
50:50	0.69	0.60	0.54
40:60	0.67	0.59 (0.52[b])	0.54

[a]US NREL (2011)

[b]Adapted from US NREL analysis

Using the net present value (NPV) economic analysis, the correlation between the ethanol production cost and equity financing is presented in Figure C-13. For a production capacity of 2000t/d, the production cost ranged from USD0.64/l to USD0.62/l with the movement of equity financing share from 30% to 70% which is higher than the current market ethanol price of USD0.58/l.

Figure C-13 also shows the variation of ethanol production cost at different capacities and with variation in enzyme costs. The plot demonstrates that economic viability from lower ethanol production cost can be achieved at favourable equity financing ratios, higher capacities (due to economy of scale) and lower enzyme costs.

Figure C-14 shows the price of ethanol for different capacities and capacity costs. The analysis compared the local scenario as presented above and the US scenario (NREL report). In US scenario, the production cost is USD0.67/l while in the local scenarios it is USD0.58/l and USD0.63/l for capacities of 1000t/d and 2000t/d, respectively. It shows that with the localised condition, the value of ethanol cost can be significantly reduced

Table C-16 presents the potential of ethanol production cost reduction by improving the debt: equity (D:E) Ratio or interest rate (iR). It is shown that at the iR of 3%, the ethanol production cost could be reduced significantly and make it competitive to current market value.

Box C- 6 Location factor for biofuel plant

Biomass valorisation had been recognised as sources for renewable energy in recent decades. Aiming at utilising biomass residues can avoid food price competition and land uses change. Nevertheless, the major cost factor of biomass supplies lies in the transportation.

The geographical heterogeneity of biomass is illustrated in Figure C-19. Each type of biomass has different spatial structure varying on the level of centrality and dispersion. Depending of the point of mill location, the accessibility to a particular resource will differ greatly and will significantly impact the transportation cost. In each diagram, Location I can access more biomass areas with less distances compare to Location II. The more distances are required; the transportation cost would be incurred.

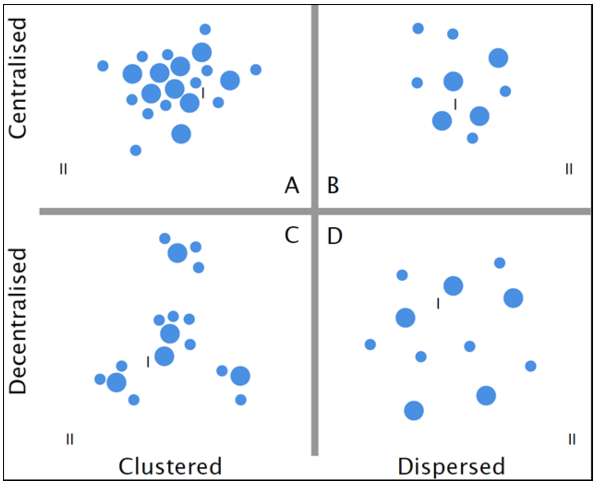


Figure C- 18 Spatial structure of biomass resources (Rodrigue, 2013)

With Euclidean distance computation and taking into account the road network in Peninsular Malaysia, the accessibility to forest, palm oil, paddy and rubber are shown in Figure 2. In each graph, the best biorefinery location is the lowest cost location to access the particular biomass. Contrary, the average location will require higher cost to get less biomass compare to the best location. The best biorefinery location can access more numbers of biomass area with less distances. In case of forest and palm oil, their spatial structures follow the patterns in Figure C-19 (a) and (b) respectively. The accessibility curves of both show that the number of biomass area are reached at accelerating rate from point of origin before its climax. For paddy, its structure follows Figure C-19 (c). Its accessibility takes a terrace-liked curve. The paddy area can be access at rapid rate for the first cluster and more distances are required prior to reach next clusters, as shown by the plateau before the subsequent slope. Lastly, the spatial distribution of rubberwood residues is very scattered. Its accessibility graph always increases steeply, implying that every rubber area required a distinct amount of distances to reach.

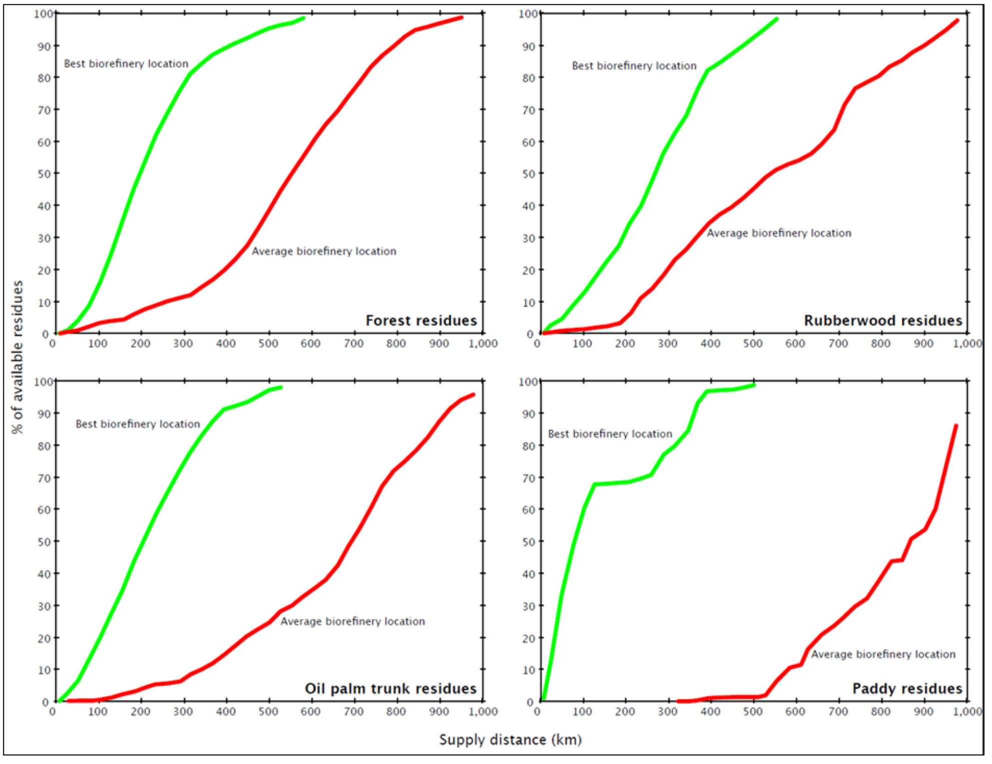


Figure C- 19 Accessibility to biomass from ideal locations and KLIA

The geographical variability of each biomass resources will affect its supply cost structure very differently. This suggests that the location factor has substantial impact on viability of biorefinery plant. It is vital to evaluate carefully the location to establish biofuel plant.

Source:

Adapted from Chu Lee Ong, Juliette Babin, Jia Tian Chena & Jean-Marc Roda. (2016) Designing model for biomass transport cost of biofuel refinery in Malaysia. Unpublished.

References:

Rodrigue, J.P., Comtois, C. and Slack, B., 2013. The geography of transport systems. Routledge. pp.191.

4.3 Conclusion

The two case studies presented in Section 4.1 and Section 4.2 review the economic potential of localised biomass-to-power and ethanol in current market. For biomass-to-power, the current FiT scheme is relatively lower than the electricity production cost, rendering the biomass-to-power option less attrative to investors. The rate of FiT scheme in Malaysia was established in year 2011, and is considered not up-to-date on current renewable resources market as various RE resources have been more economically competitative in recent years. In order to promote the utilisation of biomass to power, the current Fit should be reviewed and revised.

The case study of biomass to ethanol, on the other hand, demonstrated a favourable scenario to investors demonstrating that with a financial interest rate of 3%, ethanol production is economically competitive in the current market. Nevertheless, the current interest rate stands at the rate of 5% - 8%, and with high cost of enzyme in Malaysia, there needs to be some policy and technology intervention to enable sustainable bioethanol industry in Malaysia.

5 Challenges of Biomass Conversion in Malaysia

5.1 Investment

The challenges that hinder full-scale investment of biomass conversion technologies in Malaysia could be attributed to several factors i.e. limited access to biomass feedstock, limited financing resource for biomass conversion technologies, and lack of support from domestic market.

In the Malaysian scenario, the common agricultural practice is the reuse of biomass wastes as mulching agent in the crop cultivation sites. Coupled to the fact that there is no commodity market for biomass trading in Malaysia, the farmers/biomass owners are reluctant to accept long-term biomass supply contract due to the unfavourable pricing of biomass leading to limited availability or uncertain supply of biomass feedstock.

Secondly, advanced biomass conversion technologies i.e. fermentation (bioethanol), biochemical production, biodiesel production, gasification, and pyrolysis require relatively high investment costs and therefore long payback periods.

Thirdly, the green biomass-derived products (i.e. biochemical and biofuels) are far too expensive than the conventional fuel and products, and therefore are not supported by the local consumers. These high-end sustainable products are only compatible for premium export market, and therefore low local demand does not trigger the need for investment on biomass conversion technologies.

5.2 Technology/Technical challenges

Composting: this technology is mature and anaerobic composting process is commonly applied. However, this technology would result in large carbon footprint, and would lead to odour problem if there were no proper containment of biomass waste being composted.

Biomass-based power generation: gasification and pyrolysis are less mature than direct combustion, and have higher vulnerability to technical breakdown/ accident/ explosion due to malfunctioning. Pyrolysis process, in particular, has low thermal stability, corrosion problem, and further upgrading of bio-oil (for creating market value for the product) (McKendry, 2002a).

Biochemical and biofuel production: Biorefinery process designed to synthesise biochemical i.e. acids, bio-sugar, polylactic acid, food additives, zeolite and catalyst, etc. is still in an infancy stage in Malaysia. This is manifested by the lack of pilot/ demonstration plants, deficit of market-focused R&D, and lack of local market support for these technologies due to their high risks in term of technical and financial. IPs for conversion technologies for biochemical production are now highly prized and globally are in the domain of large private companies such as DuPont, DSM.

5.3 Transportation and logistic

Costs associated with transportation vary for different biomass residues. Biomass which are generated post processing such as empty fruit bunches, palm kernel shell and mesocarp fibres are available at the mills so transport costs from these mills to any biomass processing centres is minimised. The same is true for biomass from other crops such as rice husks from rice mills, and sawdust and wood chips from timber mills. However, for non-processed biomass such as oil palm tree trunks and frond, rice straws, and non-processed forest products, the transportation costs are a function of its distance to the transportation network. Cost estimates from the NBS report range from RM0.20 to RM 10 per kilometre per tonne based on road transport (trucks) but may differ upon the availability of other modes of transport such as trains or barges but transport interfaces need to be factored in. For long distance haulage, compression and pelletisation of biomass resource into compact forms (i.e. pellets or briquettes) would be required (BioEnergy Consult, 2016).

Box C- 7 Modelling the biomass transportation cost – case of Malaysia

The model uses raster [1] map format where the workspace consists of more than 117 million pixels of quasi-square; each square approximately 63 metre wide. First, it is started by assigning the friction cost [2] to land cover. It is estimated from regression analysis, each pixel of road requires 0.0696 km to traverse and off-road is 0.14km.

Next, 89 points of district in Peninsular Malaysia are treated as starting point to compute the Euclidean distances [3] in GRASS GIS. 89 distance maps are generated where each pixel[4] contains the cumulated distances to the starting point.

The distance maps are then multiplied with the transport cost equation to obtain transport cost (TC) map for each truck size and district. Prior to subsequent step, annual biomass residues production is computed and assigned as residues production density (ton/pixel/year) to the agriculture and forest area maps.

Then, multiplication of TC maps with the residues production density map (Forest - logging residues, Palm oil – Oil palm trunk, Paddy – rice stalk & Rubber – logging residues) will render the biomass transport cost (BTC) maps. The sum of values in each BTC map is the cost of transporting the particular biomass residues to a district. The comparison of BTC maps of each district will provide the lowest cost location for transporting the particular biomass residues.

Source:
Adapted from Chu Lee Ong, Juliette Babin, Jia Tian Chena & Jean-Marc Roda. (2016) Designing model for biomass transport cost of biofuel refinery in Malaysia. Unpublished.

Notes:
(1) Raster: A spatial data model that apply grid cells with rows and column to spaces. Each cell contains an attribute value and location coordinates.
(2) Friction cost: Value that define difficulty to crossing the cell.
(3) Euclidean distance: The straight-line distance between two cells.
(4) A pixel represents a unit of area which is approximately 4022 metres square.

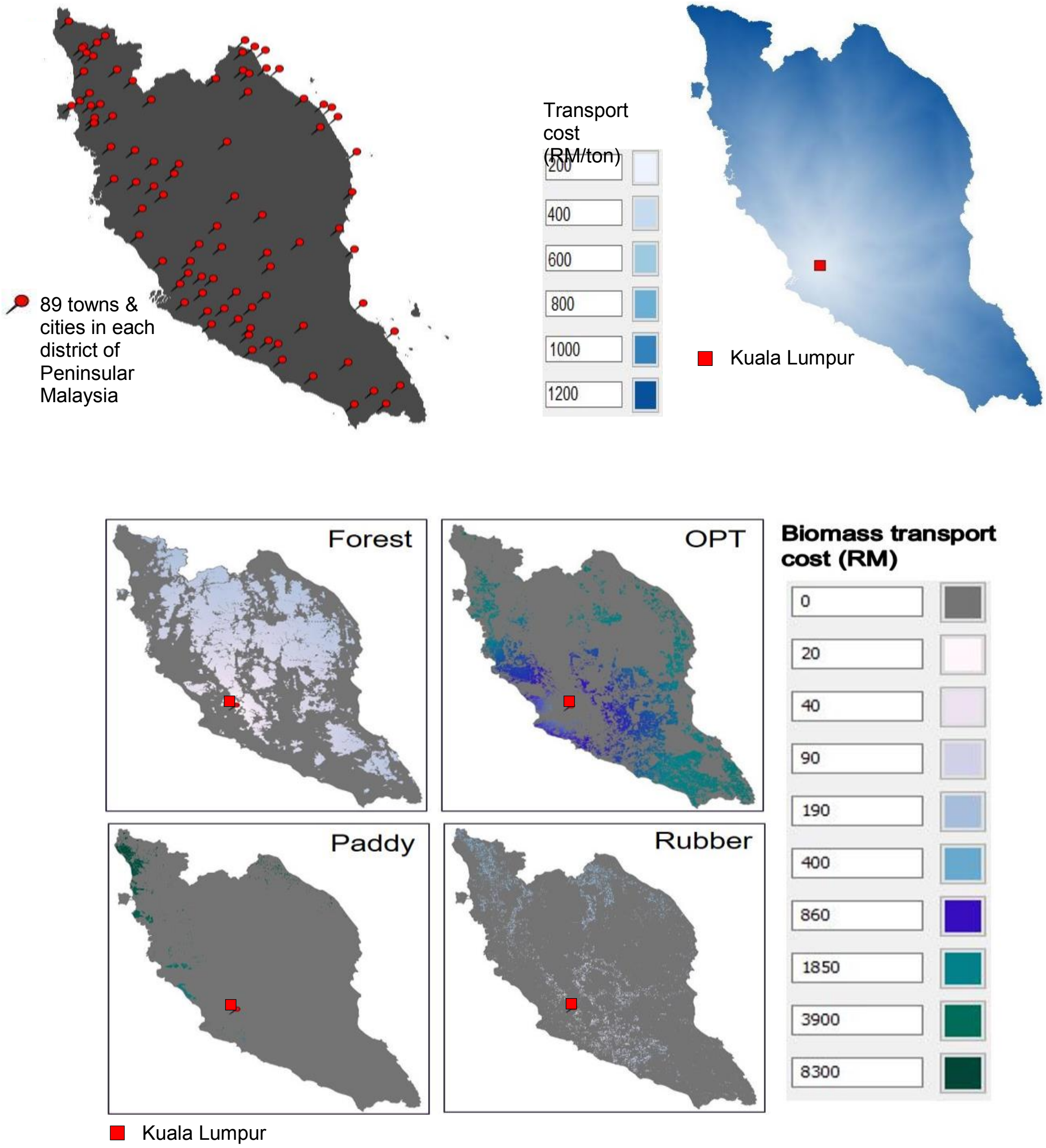


Figure C- 20 Map examples

Fig C-22 illustrates a business model that could overcome the issue of biomass handling, transportation and storage. As shown in this figure, the slashed materials from land clearing such as forest residues, oil palm tree trunks and fronds are collected by the local communities with the cooperation from small and medium enterprises. The biomass will be converted into value added products such as pellets through different technologies. First, the raw material will be pre-treated through wood processing processes such as debarking, chipping and re-chipping to stringent bark retention tolerances of the raw material. It is then gasified through gasifier to be converted into electricity. Spanner RE2 gasifiers provide heat for commercial chip drying and power for use on the site. Alternatively, the biomass can be pelletised into compact pellets which can be used onsite as fuel for a cogeneration system to produce heat and electricity or for shipment locally or internationally. Pelletised biomass has a low moisture content, regular shape and high density, which could enhance burning efficiency and is easy to transport. Spanish company PRUDESA is one of the pioneer enterprises that provides advanced technology for biomass pelletising. During cogeneration of biomass, 30 to 35% of its energy content is transformed into electrical power and 55 to 60% into useable heat. The generated heat can be used for an urban heating network, industrial processes, drying biomass and any kind of wood residues. GEMCO Energy Machinery Co., Ltd developed a machine named MPL 300, a small moveable multifunctional complete pellet plant for pelletizing production. The integrated pelletised plant which includes crushing, pelletising and cooling could improve the system efficiency remarkably, reducing pellet production costs and most importantly, overcoming the challenges of storage, handling and transportation of biomass due to logistical issues.

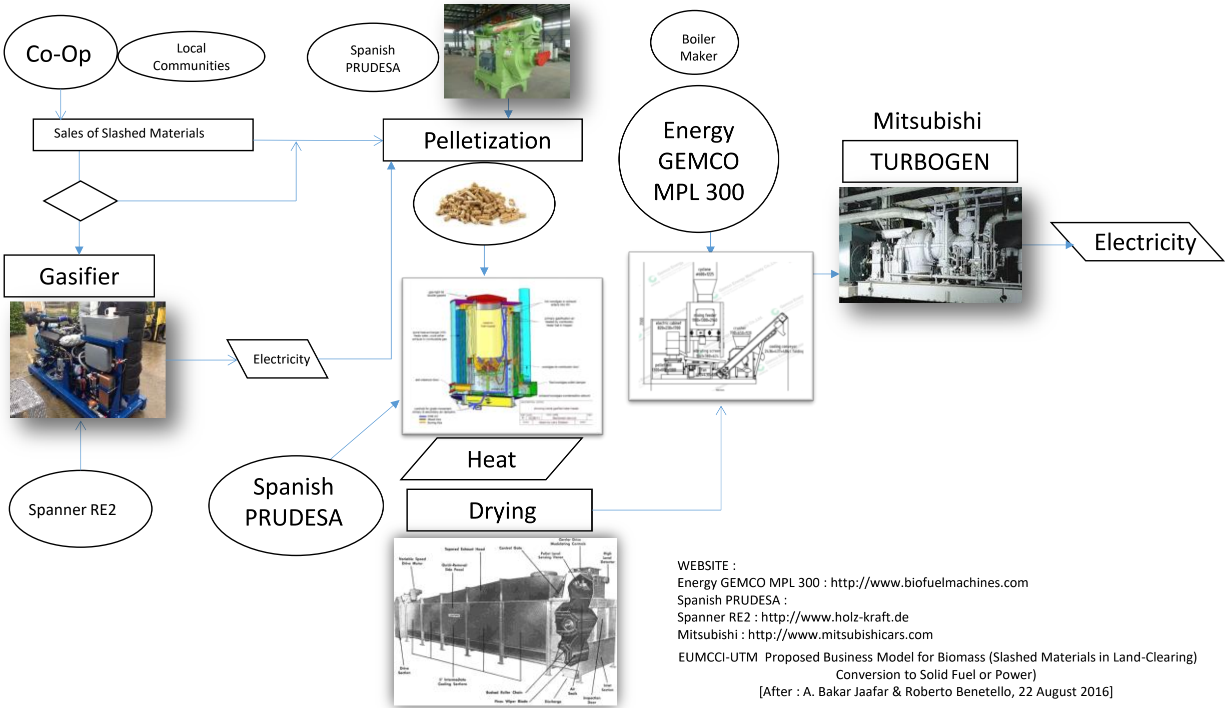


Figure C-22 Biomass to pellet business model to overcome logistical issues of biomass handling, storage and transportation

5.1 Social/ Cultural Awareness

Low awareness of achieving sustainability via maximum harnessing or reuse of biomass could be another challenge in Malaysia. Locally, the concept of carbon footprinting is adopted very slowly and sustainability is not a major concern in business decision-making.

Moreover, in Malaysia, the concept of environmental sustainability is not ingrained among the population. Among the three pillars of sustainability (i.e. economic, social, and environmental), practical engineering considerations only emphasise the first two aspects. Without the enforcement of regulations, application of biomass resources for the sake of environmental protection is not imperative for existing businesses.

Box C- 8 Shredder Initiative of Rotary Club of Lampang, Northern Thailand

Rotary Club of Lampang (Northern Thailand) is trying to provide farmers with an alternative to burning their agricultural waste in order to prepare the land for the new harvesting season. This alternative is called "Shredder Initiative" and might also lift farmers out of the poverty trap that causes them to burn in the first place.

Farmers in Lampang explained to the Rotary Club that they had no affordable alternative means of agricultural waste disposal. One of the board members of the Rotary Club designed a shredder that shreds residues into fine pieces which, when mixed with microbes become organic compost and fertilizer that can be used to enrich soil. Thai Government provides free microbe to registered farmers and in addition surplus fertilizer can be sold.

Figure C- 23 Photo of the shredder

(photo taken from www.bangkokpost.com)

The shredder is durable and can be easily carried on the back of a pickup truck. It is designed to be shared to encourage farmers to co-operate with one another and work together to achieve economies of scale.

Table C-17 Techno-economic and financial aspects of the shredder

Techno-economic and financial aspects	**Details**
Capacity	187 kg/h (tested for dried rice straw), powered by a 9HP diesel engine
Price ex-factory (based on one by one order)	USD3000 for diesel engine USD2700 for gasoline engine USD2200 without engine
Maintenance cost	USD3.2/tonne of dried rice straw
Cost for blades	USD16/blade (60 blades in total for 1 shredder)
Fuel consumption	Less than 3L/tonne of diesel oil
Diesel price	USD0.025/kg
Noise level	Below 80 dB
Other details	The blade is the most worn out part and its worn out rate will depend on the shredded material. The blades will need replacement after 350tonnes of shredded rice straw. One shredder can shred rice or corn residues produced on about 78 rai (30.8 acres) of farmland in a month (estimation).

The Rotary Club has built two shredders from their own funds. One is being shared by a group of 20 farmers over 180 rai (71.2 acres) of land. The other is being placed in a farming village comprising 25 farmers over 200 rai (79 acres) of land. The Rotary Club precondition for the utilisation of this shredder is that farmers must not use chemical fertilizers or pesticides.

6 Science and policies interface

6.1 Existing Policies

Excessive open burning of biomass has resulted in severe haze in South East Asia. Increasing the utilisation potential and market value of biomass resource is among the haze mitigation strategies that are technically and economically sound. Biomass can be converted to other products and utility that could benefit development. While biomass in Malaysia has been deemed as an important resource for sustainable development that the government is heavily promoting, the development of biomass in the country is rather slow. Among the reason is the difficulty to obtain biomass resources, expensive bio-conversion technology (conversion of biomass to other products and utility), and lack of an established market to market biomass-related products.

Apart from research centric approaches to increase the efficiency and reduce the cost of bio-technology, policies play an important role in ensuring bio-technology development and marketability of bio-products in the present.

Up to date, there are several policies established to support biomass utilisation to produce energy. Among these policies are the Fifth Fuel Policy (2000), National Bio-fuel Policy (2006), National Green Technology Policy (2009), National Renewable Energy Policy (2010), and Renewable Energy Act 2011 (Hashim & Ho, 2011). These policies are developed based on three principals, which focus on supply, utilisation and environmental.

a) Supply

To ensure the provision of adequate, secure and cost-effective energy supplies through developing indigenous energy resources both non-renewable and RE resources using the latest cost options and diversification of supply sources both from within and outside the country.

b) Utilisation

To promote the efficient utilisation of energy and discourage wasteful and non-productive patterns of energy consumption.

c) Environmental

To minimise the negative impacts of energy production, transportation, conversion, utilisation, and consumption on the environment.

i) Fifth fuel policy (2000): to promote renewable energy (RE) as the fifth fuel along with fossil fuels and hydropower. These fuels are biomass, biogas, solar, and mini-hydro.

ii) National Bio-fuel Policy (2006): to put the biofuel (particularly 5% blended palm oil) as one of the five energy sources for Malaysia.

iii) National Green Technology Policy (2009): to emphasis Green Technology (GT) as one of the key drivers of national economic growth and sustainable development (Matrade, 2011).

iv) National Renewable Energy Policy (2010): to enhance the utilisation of indigenous renewable energy resources to contribute towards national electricity supply security and sustainable socio-economic development.

v) Renewable Energy Act 2011: the establishment and implementation of a special tariff system to catalyse the generation of renewable energy.

Based on the list of policies above, Malaysia has put effort into promoting bio-based energy since more than 15 years ago; however, only until recently where Feed-in Tariff (FiT) was introduced that some investment on biomass to power is recorded. FiT is a financial scheme that was introduced to support renewable energy development, where investor of RE will be paid a certain rate per kWh of energy generation. The tariff rate for bio-energy is given in Table C-17 below (SEDA, 2016).

Table C-178 Feed-in tariff for bio energy (SEDA, 2016)

Bio-energy	Size	FiT Rates (RM per kWh)
Biomass	↓10 MW	0.31
	↑10 MW ↓ 20 MW	0.29
	↑20 MW ↓ 30 MW	0.27
Bonus for gasification		+0.02
Bonus for steam generation	↑ 20% efficiency	+0.0100
Bonus for local manufacturer		+0.0500
Bonus for MSW		+0.0982
Biogas	↓4 MW	0.3184
	↑4 MW ↓ 10 MW	0.2985
	↑10 MW ↓ 30 MW	0.2786
Bonus for gas engine	↑ 40% efficiency	+0.0199
Bonus for local manufacturer		+0.0500
Bonus for landfill or sewage gas		+0.0786
Mini-hydro	↓10 MW	0.2400
	↑10 MW ↓ 30 MW	0.2400

Even with financial aid such as the FiT, the progress of biomass implementation is rather slow. In April 2016, up to 61.4MW capacity of biomass power plant is recorded (SEDA, 2016). One of the main reasons for the slow progress in implementation is due to the difficulty in obtaining sustainable biomass resources, fluctuating price of biomass resource, and high capital cost of bio-technologies. These are often excluded when designing the policies to support biomass utilisation.

7 Way forward

Through the years, the government of Malaysia has formulated policies and programmes to ensure the long-term reliability and security of energy supply for sustainable socio-economic development of the country with varying degrees of success. The use of biomass for fertilizers and as fuel in direct combustion is now in the commercial domain, there are still challenges in moving up the value chain of biomass conversion to biochemical (which include the biofuels ethanol or butanol). The issues related to the mandates on biodiesel B5 and bioethanol E10 which hinders any hope of full uptakes on any bioethanol investment. Without a firm biofuel policy mandate the case for bioethanol is hard to defend due to its high investment cost. The problem is further compounded when the investments is undertaken through the acquisition of bank loans thus increasing the operational cost from interest payment. It is proposed that there is a significant funding involvement from the government converted to equity to minimise the interest charges from massive loans. The equity-loan ratio needs to be optimised to maximise margins on sale of ethanol from a financial evaluation. The economic case for biopower or bioethanol is not helped by the imperfect development of the local biomass market into a full-fledged commodity market.

The biomass market in Malaysia is quite fragmented and unorganised. In order to ensure proper management and trading of biomass, a centre for sustainable mobilisation of biomass resources is proposed to be established which include biomass logistic and trade centres. The centres are regional centres with optimised logistics and trading organisation, where different biomass fuels such as firewood, chips, pellets, and energy crops are marketed at guaranteed quality and prices.

7.1 Policies Recommendation

In order to further boost the potential of biomass utilisation, the current policies have to be improved and enhanced. In general, other than biomass power, other sort of biomass product should be given governmental support such as biomaterial, biofuel, etc. The policies should be developed for i) securing biomass resources, ii) supporting biotechnologies, and iii) platform for biomass product marketing.

i) Securing biomass resources

Malaysia has abundant of biomass resource from the agricultural sector and is mostly controlled by the corresponding agriculture company. This leads to an unstable pricing environment of biomass resources and rendering high risks to the biomass utilisation investment. Additionally, biomass is found all over the country at different places and at a different quantities causing difficulty in estimating the biomass acquiring cost such as transportation of biomass, its quantity and even quality.

It is proposed that a stable source for biomass data should be made available. The Malaysia Government should initiate a programme to conduct studies on total biomass supply chain within the country; identifying the type, location and amount of available biomass that can be used for production of value-added products.

It is further recommended that the Malaysian government develop and regulate a stable pricing mechanism of biomass like any other commodities to ensure a stable and sustainable market for biomass.

In Thailand, The Department of Alternative Energy Development and Efficiency (DEDE) under Ministry of Energy is responsible to study the potential of biomass database development in order to determine the amount of biomass available in different areas as well as overseeing the use of biomass for energy production. The database system is developed using GIS technology. Biomass database is necessary for the policy / strategy and action plan to promote the use of biomass, to set an appropriate action plan and to know the size and capacity of biomass fuel in areas that are suitable to invest (DEDE, 2016).

In United Kingdom, wood pellets for heating is governed by the UK Pellet Council (UKPC). The UKPC is a trade body, hosted by the Renewable Energy Association (REA). Through the UKPC, the ENplus quality certification is introduced. The ENplus quality certification replaces numerous national standards and certification for wood pellets into one uniform system. The system encompasses standards throughout the entire supply chain, from production, storage, transportation to the end consumer (UK Pellet Council, 2016).

ii) Supporting technology development

Conversion technologies of biomass to resources are often expensive with high maintenance cost and a long investment rate of return. High yielding conversion technologies need to be developed to improve returns and encourage investment. Furthermore the technologies need to be developed locally with local IP ownership to minimise the technology acquisition costs. This requires an increase in research funding in biomass technology. Other moves from the government to provide more fiscal incentives for biomass based research and development activities would also be welcomed.

iii) Platform for biomass product marketing

Many products can be produced from biomass resources, however, they often have to compete with existing products which are generally cheaper. Apart from subsidies, the government can also establish a platform where these bio-products can be marketed much like the EU-Malaysia Biomass Sustainable Production Initiative (Biomass-SP) which was developed in Malaysia to undertake more intensive promotion on biomass.

Biomass-SP was developed with an aim to be a one-stop centre to promote biomass utilisation focusing on sustainable biomass consumption and production in Malaysia. Biomass-SP has organised several activities, listed below, since 2012 to bring together stakeholders and experts to share their experience in biomass advancement (Biomass-SP, 2016).

a) EU-Asia Biomass Best Practices & Business Partnering Conference 2012 and 2013

b) Briefing Session for Financial Institutions (FIs) and Development Financial Institutions (DFIs)

c) EU-Malaysia Biomass Entrepreneurs Nurturing Programme (EUM-BENP)

7.2 Further area of Biomass research and development

In spite of various current policy and initiative on the biomass utilisation industry, the current research and development on the potential biomass utilisation is still in the infancy stage. Several recommendation on the biomass research and development is discussed for i) biomass database and support, ii) biomass research funding.

i. Biomass Database and Support

Firstly, a database to identify the standards requirements, quality, quantity and location of biomass should be established. In order to govern the mobility and utilisation of these resources, a governmental agency should be designated to regulate and manage the supply chain of palm oil and forest biomass residues within the country from production, storage, transportation, to utilisation.

ii. Biomass Research and Development

To improve the efficiency of conversion and reduction of technology cost, the Malaysian Government should allocate specific funding for supporting the research and development on biomass conversion technologies. Among the areas of research recommended are:

- Biomass to material and energy supply chain
  The study of biomass conversion to products supply chain should include transportation network, location of the (potential) biomass production sites, storage facilities and conversion facilities
- Spatial optimisation study
  Integrated GIS with optimisation model enable efficient planning of conversion biomass to products. These spatial models were based on publicly available data, regional biomass potentials and regional heat and electricity demands. Spatial models provide geographically specific input data for the optimisation to determine the cost effective technology, capacity and optimal location of biomass conversion plant.
- Biomass to energy
  Techno-economic analysis should not be limit to conversion of biomass to electricity and heat only but can be extent to other potential products such as biomass pellet, biochar etc.
- Development of pre-treatment technologies for various types of biomass residues.
  There are numerous biomass residues in the region, each with their own specific characteristics, that one single technology will not be able to fit all biomass residues. The pre-treatment technologies to be applied are very important as it determines the important parameters (size, substrate inhibition) for successful and efficient enzymatic hydrolysis in biochemical conversions. Some residues contain oils and wax such as EFB, while others contain high composition of silica such as rice husks and rice straws. Others contain leafy residues such as palm oil fronds and forest undergrowth residues. There are also some residues which contain other valuable materials which need to be extracted out prior to any pre-treatment processes.
- Enzyme research study
  Enzyme producing research needs to be developed and strengthened to enable an economically viable technology to emerge locally to benefit the biomass industry.
- Development of microorganism

Development of microorganism, natural or genetically modified, for conversion of biomass to higher value biochemical, such as succinic acid, furan dicarboxylic acid, glycerol or butanediol. These biochemicals command a higher unit price than bioethanol although the market demand is also smaller. Most of them are still in pilot or demonstration plant phase giving Malaysia time to develop the required technologies.

For power generation, investor can apply FiT; however, to ease the application and support haze mitigation strategies, a separate allocation of biomass FiT quota should be in place for usage of palm oil frond and/or forest residue.

Other than power generation, the Malaysian Government should also promote other useful bio-products especially biodiesel and bioethanol. The Malaysian Government can establish a policy for a specific blending of gasoline that utilisation bioethanol. An example of such policy is implemented in the US.

In US, the government had developed The Clean Air Act Amendments of 1990, which requires the use of oxygenated or reformulated gasoline (RFG). The Energy Policy Act of 2005 established a renewable fuels standard (RFS), which mandates the use of ethanol and other renewable fuels in gasoline. Approximately 99% of fuel ethanol consumed in the US is E10 (blends of gasoline with up to 10% ethanol) and about 1% is consumed as E85 (85% ethanol and 15% gasoline). Therefore, ethanol is primarily used in gasoline to meet a minimum oxygenate requirement for RFG thus made significant changes to the development of the US ethanol industry market (Wesley P. Leland, 2009).

7.3 Conclusion

One of the root causes of the haze is the 'traditional' annual slash and burn practice in our neighbouring country to clear the undergrowth and vegetation to plant crops. The motivation to burn is because it is the most economical method and cheapest form of land clearance.

Although economic return is one of the main causal factors for the regional haze occurrences, it is probably a great motivator for moving away from traditional methods of land clearing which does not yield any economic benefits. As haze episodes may evolve into potentially complex emergencies, the development of an effective technology for biomass utilisation is critical. From the above detailed discussion, turning waste into vaue-added products such as compost, fuel, power, and biochemical will create an economic benefitsand utimately reduce the open burning practices and prevent the haze issue. The choice of technology or combination of technologies to be selected for possible demonstration or even commercialisation requires a more detailed study. This is to determine with greater accuracy on the investments needed and the possible economic returns to complement the social and environmental benefits of the solution.